

Agricultural intensification and efficiency in the West African savannahs: Evidence from northern Nigeria

Socio-economic and Policy Research Working Paper 33

I. Okike, M.A. Jabbar, V. Manyong, J.W. Smith, J.A. Akinwumi and S.K. Ehui

International Livestock Research Institute
P.O. Box 30709, Nairobi, Kenya

International Institute of Tropical Agriculture
PMB 5320, Ibadan, Nigeria

University of Ibadan
UI Post Office, Ibadan, Nigeria

Working Papers Editorial Committee

Mohammad A. Jabbar (Editor)
Simeon K. Ehui
Steven J. Staal

LPAP working papers contain results of research done by ILRI scientists, consultants and collaborators. The author(s) alone is (are) responsible for the contents.

Authors' affiliations

I. Okike, International Livestock Research Institute (ILRI), P.O. Box 5689, Addis Ababa, Ethiopia
M.A. Jabbar, ILRI, P.O. Box 5689, Addis Ababa, Ethiopia
V. Manyong, International Institute of Tropical Agriculture (IITA), PMB 5320, Ibadan, Nigeria
J.W. Smith, ILRI, P.O. Box 5689, Addis Ababa, Ethiopia
J.A. Akinwumi, University of Ibadan, UI Post Office, Ibadan, Nigeria
S.K. Ehui, ILRI, P.O. Box 5689, Addis Ababa, Ethiopia

© 2001 ILRI (International Livestock Research Institute)

All rights reserved. Parts of this document may be reproduced without express permission for non-commercial use but with acknowledgment to ILRI.

ISBN 92-9146-096-6

Correct citation: Okike I., Jabbar M.A., Manyong V., Smith J.W., Akinwumi J.A. and Ehui S.K. 2001. *Agricultural intensification and efficiency in the West African savannahs: Evidence from northern Nigeria*. Socio-economics and Policy Research Working Paper 33. ILRI (International Livestock Research Institute), Nairobi, Kenya. 54 pp.

Table of Contents

[Acknowledgements](#)

[Executive summary](#)

1 Background and objectives

2 Agricultural intensification and crop–livestock interactions in sub-Saharan Africa

2.1 Existing hypotheses about intensification

2.2 Hypotheses and indicators of intensification for this study

2.3 Study area, sampling and data

2.3.1 Study area

2.3.2 Sampling and data collection

2.4 Analysis, results and discussion

2.4.1 Specification of the empirical model

2.4.2 Results and discussion

2.4.2.1 Land use intensity

2.4.2.2 Labour intensity

2.4.2.3 Rate of application of manure per hectare

2.4.2.4 Animal traction days used per hectare

2.4.2.5 Rate of application of fertiliser per hectare

2.4.2.6 Number of tropical livestock units per hectare

2.4.2.7 Livestock cash income in gross revenue

2.5 Summary

3 Factors affecting farm-specific economic efficiency: Application of frontier production function

3.1 The theoretical model

3.2 Specification of the empirical model and definition of variables

3.3 Results and discussion

3.3.1 Differences in economic efficiency among classes of farms

3.3.2 Productivity of farm inputs

3.3.3 Economic inefficiency effects

3.3.4 Characteristics of most efficient and least efficient farms

3.4 Summary

4 Assessing potential for improving efficiency: An extension of the frontier model

4.1 Specification of the model

4.2 Results and discussion

4.3 Quantifying the impacts of alternative resource use options

4.4 Summary

References

Acknowledgements

The authors are grateful to Timothy O. Williams and Steven Staal for valuable comments and suggestions on an earlier draft, and to Mohammed A. Ahmed and Garth Holloway for comments on specific sections of an earlier draft. Fieldwork was funded by ILRI while the first author was a Graduate Fellow with the consumption-to-production systems project in West Africa. Additional funding was provided by the System-wide Livestock Programme to undertake further analysis and publish this document.

Executive summary

Agricultural intensification in West Africa is in its early stages and several hypotheses have been postulated about its evolution and possible pathways. In addition, farm efficiency may vary across farms and other socio-economic domains, opening opportunities to improve efficiency and productivity through reallocation of current resources and introducing new technologies that target farmers. A survey was conducted among 559 households in 8 villages, 4 each in the northern Guinea savannah (NGS) and Sudan savannah (SS) zones of northern Nigeria, each representing a combination of high or low population density and high or low market access, to test these hypotheses.

Analyses show that, in general: (a) ecology, population density and market access and their interactions are important drivers of agricultural intensification, manifested both in terms of higher levels and/or intensity of use of various production inputs, and interaction and/or integration between crop and livestock in the various socio-economic domains that represent their interactions; (b) as one moves from low-population–low-market access domains to high-population–high-market access domains, the degree of intensification increases and the principal means of intensification changes from increased intensity of use of farm resources (land, manure, labour and traction) to increased intensity of use of commercial inputs (e.g. fertilisers) and sale of outputs; (c) the degree of intensification is higher in the Sudan savannah zone than in the northern Guinea savannah zone. In addition to the interaction of population pressure and market access, several variables such as farm size, herd size, experience in mixed farming, family size, farm types and proportion of legume crop in cropping pattern significantly influenced the intensity of use of specific inputs.

The results indicate that policies to enhance market access for products and inputs will facilitate the process of intensification and crop–livestock interaction. In the context of the well known benefits of crop–livestock interactions and integration to sustainable agricultural production, the incorporation of high value livestock products into mixed farms should be actively promoted to counter-balance the higher ratios of household cash income accruing from the sale of high value crop products in order to maintain the interest of farmers in the crop and livestock components of their mixed farms and avoid 'early specialisation' of the systems.

Using frontier production function to measure farm-specific efficiency, parameter estimates for factors of production and inefficiency effects were obtained and the farms were characterised according to their economic efficiency ratings. The results show that a positive relationship exists between agricultural intensification and economic efficiency and that food production in West Africa could be significantly boosted through improving the economic efficiency of farms by utilising existing resources as well as introducing improved technology.

The application of the stochastic frontier function was extended by substituting a logistic regression model for the linear equation conventionally used in the second stage of the stochastic frontier technique to determine inefficiency effects. This analysis confirmed the hypothesis that manure is the hub of crop–livestock interactions, being the most influential of available resources for improving farm economic efficiency. Improving manure supply would involve evolution of pastoral to mixed farming or crop farming to mixed farming and an initial decline in the share of livestock or crop income in gross revenue of farms. However, this deficit is more than compensated for by an overall improvement in farm economic efficiency, which translates into a significant increase in gross revenue of farms. Modelling to quantify the effects of alternative technology and institutional interventions and comparing farms that use

manure with those that do not showed that intensifying manure use at the current stage of agricultural practices by similar units always resulted in a higher probability of operating at above average economic efficiency for farms that use manure than those that do not use manure.

1 Background and objectives

Agricultural intensification may be defined as 'increased average inputs of labour or capital on a smallholding, either cultivated land alone or on cultivated and grazing land, for the purpose of increasing the value of output per hectare' (Tiffen et al. 1994). The intensification process can be said, in practice, to result from:

- an increase in the gross output in fixed proportions due to inputs expanding proportionately, without technological changes
- a shift towards more valuable outputs or
- technical progress that raises land productivity (Carswell 1997).

Agricultural intensification and technical change have followed different paths in different parts of the globe. According to the theory of induced innovation, the nature of technical change in a given society will be induced by the endowment of resources, particularly land and labour, reflected in their relative prices, and their relation to product prices (Hayami and Ruttan 1985).

In a significant part of sub-Saharan Africa (SSA), particularly in West Africa, agriculture is at the early stages of intensification. Several hypotheses have been postulated explaining the process and driving forces for agricultural intensification in SSA (Boserup 1965; McIntire et al. 1992; Smith et al. 1993; Jabbar 1996; Manyong et al. 1996; Okoruwa et al. 1996; Ehui and Jabbar 1997; Smith et al. 1997), yet the possible pathways of intensification in the region are still not clear. A better understanding of the pathways and driving forces for intensification will help to design research, policy and institutional mechanism to facilitate beneficial outcomes from the process.

A better understanding of the possible pathways of development in SSA is important because in this continent human population is growing more rapidly than in any other region of the world. Its population of 0.5 billion in 1990 is projected to reach 1.3 billion by 2025.

Urbanisation is also occurring and incomes are increasing, expanding the demand for food. Furthermore, Africa is often cited as the only developing region where agricultural output and yield growth is lagging seriously behind population growth (Savadogo et al. 1994; Islam 1995). In SSA, for example, population doubles every 25 years while agricultural productivity has, in fact, declined from 1.9% to 1.5% during the past 15 years (World Bank 1997). One way of solving the problem of food shortage is to increase agricultural productivity via technical change and/or improving the efficiency with which farmers use available resources.

Achievement of these objectives will require the development of efficient markets, investment in rural infrastructure and the distribution of agricultural inputs, e.g. seeds and fertilisers. It is also conceivable, however, that technical change could only be considered a more appropriate option when efficiency in utilising existing resources is very high among users thus limiting the scope for increasing productivity through reallocation of current resources.

The problem is that livestock population is also expanding and these pressures on a fixed land base are likely to promote severe competition for resources and drive agriculture progressively towards intensification. In this context, greater interaction between crop and livestock enterprises may offer possibilities for increasing production and productivity through exploiting their synergies, e.g. crop residues become the dominant feed resource just as manure becomes increasingly important in soil fertility maintenance (Winrock 1992). A combination of population pressure and market access have also been said to trigger agricultural intensification and crop–livestock interactions.

The food production potentials of the subhumid and wetter part of the semi-arid agro-

ecological zones of SSA have been recognised and identified for research priority (Winrock 1992). These zones correspond to the NGS and SS zones of West Africa. Moreover, some new agricultural technologies have been introduced in these zones. These technological packages are often of a general nature, yet they are targeted at farms and communities in different ecologies and at different levels of development of infrastructure and human capital, e.g. access to markets, education, experience and technical skills. Consequently, they perform differently in the different locations and the overall outcomes fall short of the potential. In the dissemination of new technologies, farmers in the region are treated as though their constraints and opportunities are similar. Such approach is also adopted in applied research where a majority of farm productivity studies generally stratify farms only by farm characteristics, e.g. farm size, tenure and level of income, and go ahead to measure efficiency for the average farm. Such methods presume that all farms produce under similar conditions, and as such the differences in output and productivity among farms is mostly due to the scale of operation. A methodology that ignores the environment, in which the farms operate—biophysical conditions, population pressure and market access—and their implications for farmers' resource allocation and consequent productivity, could be misleading.

A relevant question then is, if ecology, population pressure and market access induce agricultural intensification and crop–livestock interactions in these zones, do these forces also induce higher efficiency in resource use leading to higher output per unit of resources applied? If so, what is the extent of efficiency gains that can be achieved either by reallocating resources or by improving technology, and what is the mechanism through which such potential gains can be translated into reality?

The objectives of this document are threefold:

- to test the selected hypothesis and identify some indicators of the possible driving forces of intensification in the region
- to test the hypothesis that there are differences in efficiency of farms between the two ecological zones and between farms in each zone
- to identify factors that contribute to such efficiency differences and simulate the effects of some technology and resource use options on potential improvement in efficiency of less efficient farms.

In Chapter 2 of this paper, some existing hypotheses are summarised, specific hypotheses about driving forces and indicators of intensification are postulated, and the study area where the hypotheses were tested is described along with the sampling procedure for data collection. The empirical model is specified and the hypotheses are tested using an econometric approach. The results of this analysis are then presented and discussed. In Chapter 3, a brief review of literature on the measurement of economic efficiency is made followed by specification of the econometric model for measuring farm-specific efficiency for this study. The results of this model are also presented and discussed. In Chapter 4, factors contributing to efficiency differences found in Chapter 3 are identified and the efficiency model is extended to assess the likely effects of some scenarios for changes in technology and resource use options for achieving higher economic efficiency.

2 Agricultural intensification and crop–livestock interactions in sub-Saharan Africa

[2.1 Existing hypotheses about intensification](#)

[2.2 Hypotheses and indicators of intensification for this study](#)

[2.3 Study area, sampling and data](#)

[2.3.1 Study area](#)

[2.3.2 Sampling and data collection](#)

[2.4 Analysis, results and discussion](#)

[2.4.1 Specification of the empirical model](#)

[2.4.2 Results and discussion](#)

[2.4.2.1 Land use intensity](#)

[2.4.2.2 Labour intensity](#)

[2.4.2.3 Rate of application of manure per hectare](#)

[2.4.2.4 Animal traction days used per hectare](#)

[2.4.2.5 Rate of application of fertiliser per hectare](#)

[2.4.2.6 Number of tropical livestock units per hectare](#)

[2.4.2.7 Livestock cash income in gross revenue](#)

[2.5 Summary](#)

2.1 Existing hypotheses about intensification

One of the earliest hypotheses about the evolution of production systems was that population pressure would induce agricultural intensification and that this would be reflected in smaller holdings and increased land use intensities, e.g. shorter fallow periods to regenerate fertility and more frequent annual cropping (Boserup 1965; Boserup 1981). de Wilde (1967) postulated that apart from population pressure, market access, presence of cash crops such as cotton, or dominance of cereals in the cropping pattern might induce intensification in crop production and crop–livestock interaction, particularly adoption of animal traction, in specific situations.

Ruthenberg (1980) considered population pressure as the main driver for intensification and classified seven¹ types of production systems, which would move from less to more intensive cultivation methods. However, no integral role for livestock was defined in these systems, notwithstanding their presence, implying that intensification in crop production might proceed without significant interaction and integration with livestock.

1. The seven systems are: i) shifting, ii) fallow, iii) ley and dairy, iv) permanent upland cultivation, v) arable irrigated farming, vi) perennial crops, and vii) grazing systems.

Other authors (Pingali et al. 1987; McIntire et al. 1992; Winrock 1992; Smith et al. 1993) considered population pressure and market access to be the principal driving forces for both intensification in crop production and fostering crop–livestock interaction and integration. Some of these authors have characterised the role of livestock in intensification as an evolutionary process. They postulate that population growth increases the area of cropland through forest clearing, encroachment into traditionally used pastureland and shortened fallow periods thus making external inputs necessary to maintain soil fertility. Where livestock are available, farmers paddock animals on crop–land or otherwise collect and use manure and graze crop residues. As population pressure increases further, more intensive technologies including heavier applications of manure and fertiliser are required to increase production. A shift from paddocking to collection, processing and incorporation of manure takes place. Herders increasingly use crop residues, become settled and engage in crop production. Then the grazing of natural pasture falls, crop residues are harvested and preserved for feeding, and manure is more intensively used. Farmers may also grow legumes and forages to improve soil fertility, crop yield and livestock productivity. Finally, human labour may be replaced by traction and mechanisation, if labour costs increase in real terms due to increase in employment opportunities outside the farm.

In West Africa, the northern and southern Guinea savannahs (subhumid zone) and the Sudan savannah (higher rainfall part of the semi-arid zone) are said to have the highest potential for crop–livestock farming

(Winrock 1992). Yet, the linear evolutionary process of crop-livestock interaction and integration postulated by Pingali et al. (1987) and McIntire et al. (1992) may not equally hold everywhere. Crop-livestock interaction and integration are evolving in varying degrees across ecological gradients of the region and the process may be slightly more advanced in the drier regions because of the greater possibility of settled or semi-settled crop–cattle production in a more disease-free environment. In fact, high disease challenge to livestock from the NGS southwards appears to be a major reason why the rate and extent of crop–livestock interactions and integration have not, as might be expected, advanced rapidly. Also, many local situations in terms of driving forces, production potential and other ecological or socio-economic conditions may lead to alternative or sub-pathways for intensification (Jabbar 1996). Okoruwa et al. (1996) have shown that relative profitability and competition for resources between crop and livestock would play a significant role in determining the pace of evolution of mixed farming in specific situations.

2.2 Hypotheses and indicators of intensification for this study

Based on the above, we hypothesised that biophysical peculiarities of ecological zones (ecology), population density and market access are the most important drivers of agricultural intensification and crop–livestock interaction. Intensification may depend more on the interaction among the three drivers rather than any driver playing a dominant role. Within an ecozone, higher degree of crop–livestock interaction and intensification may be observed as one moves from low-population–low-market access situations to high-population–high-market access situations. However, the process may not follow a linear path. In some situations, improved market access may induce intensification before population pressure becomes a significant factor while in another situation, population pressure may induce intensification to a certain degree even before market access becomes a significant driver.

To test the above hypothesis, we used the following indicators of intensification and crop–livestock interaction:

- Land use intensity: Boserup (1965), Ruthenberg (1980), Boserup (1981) and McIntire et al. (1992) have postulated increased land use intensity due to population pressure as the most important and visible sign of intensification in SSA agriculture. The intensity may be manifested in reduced fallow period to replenish fertility, reduced production cycle (cropping plus fallow period), increased cropping frequency per year or production cycle (double or triple cropping).² In this study, the FAO (1980) classification is adopted; therefore, NGS and SS correspond to the moist and dry semi-arid zones, respectively. To capture some of these possibilities in this study, land use intensity has been defined as the number of continuous cropping cycles (i.e. number of years of continuous cropping × number of crops grown per year) before putting land into fallow.
- Labour intensity (persondays/ha) for crop and livestock production.
- Manure (kg) applied per hectare.
- Chemical fertilisers (kg) applied per hectare.
- Animal traction (animal days) used per hectare.
- Tropical livestock units (TLU) per hectare.
- Share (%) of livestock in farm cash income.

2. Each one of these indicators of land use intensity has advantages and disadvantages. For example, in a shifting cultivation area, fallow period may have reduced from 5 years to 3 years indicating intensification but this might have occurred with or without an increase in the number of cropping years, so the production cycle either remained the same or changed. In the same way, a production cycle may have changed with or without an increase in the frequency of cropping in a given year, so the cropping cycle either remained the same or changed.

2.3 Study area, sampling and data

2.3.1 Study area

The study was conducted in northern Nigeria covering two agro-ecological zones—the NGS and the SS.³ These zones lie between latitudes 8° and 13.5°N. Mean annual rainfall ranges from 500 mm in its northern fringes to 1600 mm along its southern boundary. Rainfall is unimodal and allows 75–180 days growing period across the gradient—north to south. There are distinct and striking differences in farming practices between the two zones. For example, the NGS or moist semi-arid zone is a maize belt in which sorghum becomes important only towards its drier northern margins while in the SS or the dry semi-arid, sorghum and millet are the major cereals grown in combination. In the SS millet assumes higher importance as one moves towards its northern fringes. In effect, the study area could also be defined in terms of a maize belt to the south and a sorghum/millet belt to the north corresponding roughly to the NGS and SS, respectively (Figure 1).

3. Jahnke (1982) and McIntire et al. (1992) classified the area in the semi-arid zone with 90–180 days growing period while FAO (1980) divided it into dry semi-arid (75–119 days growing period) and moist semi-arid (120–179 days

growing period). In this study, the FAO (1980) classification is adopted; therefore, NGS and SS correspond to the moist and dry semi-arid zones, respectively.

Cattle, sheep and goats are the predominant livestock species reared in both zones. Most farmers cultivate crops and own livestock in varying degrees of combination. The NGS has higher cropping potential and is used traditionally by herders from SS as a dry season grazing area while the SS has higher number of livestock per person with lower cropping potential.

Crop-based farmers are traditional landowners with two to four work bulls and a number of small ruminants. They depend on manure (from own stock and from purchases) a great deal to maintain soil fertility. Their relatively large farms offer them a reasonable abundance of crop residues, so the tendency for this group is to acquire more livestock to utilise the residue and save them the cost of purchasing manure—even if they could do this from the proceeds of selling the crop residues. Among this group, also, there are some who keep only a limited number of small ruminants lacking in the skill for large ruminant rearing. This latter group is involved in crop residue and manure exchange contracts with pastoralists—maintaining soil fertility mostly through crop–livestock interaction rather than integration. An emerging trend is that the manure market has extended beyond farmer-to-farmer, as frequently described, to abattoirs. At the time of this study, manure collected at abattoirs that used to constitute a disposal nightmare, was already selling for the equivalent of US\$ 8.2/t and indications are that the price will continue to rise given the tendency for contemporary government policies to withdraw subsidy on chemical fertilisers. Obviously, not many farmers have access to this source of manure since the number of animals slaughtered will depend on population and market access. Another source, outside farmer-to-farmer exchanges, is major livestock markets. There is a growing number of entrepreneurs who originally sold forage to livestock traders and served as intermediaries for livestock purchases. As additional business, this group now gathers manure from the market for sale. Again, access to manure from this source is logically limited to nearby farmers who are able to afford transport facilities or absorb associated transportation costs.

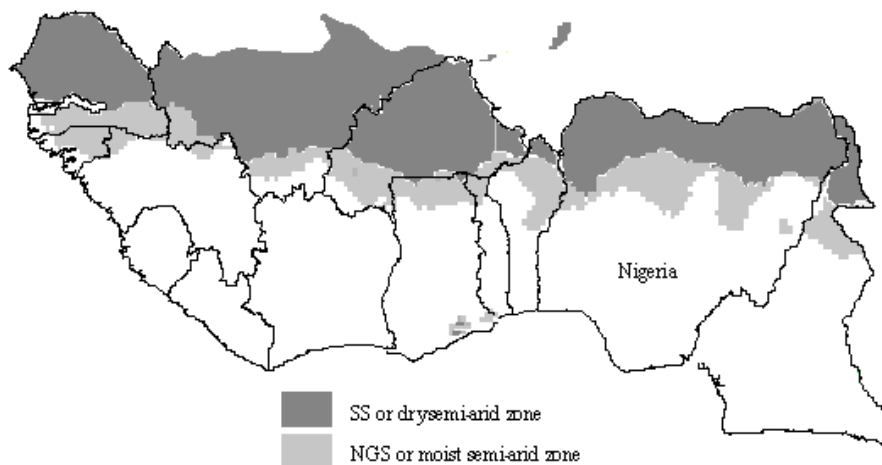


Figure 1. Northern Guinea savannah (NGS) and Sudan savannah (SS) agro-ecological zones of West Africa.

Livestock-based farmers are mostly former transhumant pastoralists who acquire small farm plots, as they begin to settle, to produce cereals for home consumption and for making some milk products that they sell. These small farms produce too little crop residue for their large herds to survive on but they benefit from relative surplus of manure deposited around the homestead—usually part of the farm—by their livestock after extensive grazing on rangelands. They also exchange manure for crop residue with crop farmers through paddocking on the crop farmers' plots. As encroachment on rangelands by crop farming occurs with increased population, this group has to depend more and more on production, exchange and purchase of crop residue as feed resource. Sale of livestock allows them to meet family expenses. Once settled, they tend to acquire more land and produce as much of their cereal and crop residue requirement as possible.

Crop–livestock integration for crop-based farmers in the savannah regions of West Africa, therefore, involve acquiring more animals and leasing or selling off less fertile parts of their farmlands. On the other hand, livestock-based farmers sell some animals and acquire these plots knowing they have the resource—manure—to restore and sustain the fertility of their plots. Thus, for these farm types, crop–livestock integration means land-for-livestock and livestock-for-land exchanges to arrive at fairly stable, single-household-owned, mixed crop–livestock systems.

2.3.2 Sampling and data collection

To focus strategic and diagnostic research for generating technologies targeted at specific recommendation domains, the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, has delineated and

characterised selected villages within a benchmark site in the NGS zone of Nigeria essentially on the basis of resource use intensity for agricultural production and the underlying influences of human population density and access to market (Manyong et al. 1996). As a rule, areas with fewer than 150 persons/km² were regarded as low population locations while the market access was defined in terms of travel time to the nearest wholesale market on a year-round basis (FDL & PCS 1992; Brunner et al. 1995). The International Crops Research Institute for the Semi-arid Tropics (ICRISAT), Kano Station in Nigeria, followed and conducted a similar characterisation exercise for the SS zone (Ogungbile et al. 1998). There is considerable interaction between population and market access, e.g. high population density could attract markets and roads to a location. For this reason, villages within the benchmark sites in each of the two zones were classified broadly into four domains representing population and market interactions as follows: low population and low market access (LPLM); low population and high market access (LPHM); high population and low market access (HPLM); and high population and high market access (HPHM) (Okike 2000). Hence, there are eight domains in the two ecozones.

From each of the benchmark sites in the two zones, four villages representing the four domains were selected purposively for this study. From the selected villages, 559 households were selected randomly from comprehensive lists of households available from village/district heads. Data were collected during February–March 1998 using a detailed and structured questionnaire.

2.4 Analysis, results and discussion

2.4.1 Specification of the empirical model

Although combinations of ecology, population pressure and market access were hypothesised as principal driving forces for intensification, there are other determinants, e.g. farm size, herd size, household size, number of years of experience in mixed farming, level of capital investment per hectare, labour allocation to crop and livestock enterprises, that could influence the specific indicators of intensification. Thus, a model was needed which would easily isolate and separate the effects of the main driving forces (the socio-economic domains) from those of the other factors.

The analysis of covariance (AnCov) technique was considered suitable for this. AnCov is a combination of classical linear regression and analysis of variance (ANOVA), and can be used to examine the effect on a dependent variable of a set of factors, each with different levels, and a set of covariates (continuous variables). Thus, the general form of the model may be written as:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_k X_{ik} + \phi_2 Z_2 + \phi_3 Z_3 + \dots + \phi_n Z_n + \epsilon_i \quad (1)$$

where Y_i is any dependent variable (any indicator of intensification), X_s are covariates, Z_s are factors each with at least two categories, β and ϕ are parameters to be estimated. A full factorial model will include all possible main-effect and interaction terms but it usually suffices to include only the relevant interaction terms along with all main-effect terms. For example, if Y is the observed measure of agricultural intensification, e.g. labour use per hectare, that depends on market access (low and high) as a factor and farm size as a covariate, then AnCov measures if labour use is significantly different between the two market access domains when the effect of farm size is controlled for. The advantage of AnCov over simple regression is that the former does not only show the direction of the difference between factors but actual magnitudes of the differences as well (Norusis 1993).

Bearing in mind that some of the indicators of intensification were used as dependent variables in some equations and independent variables in others, a problem of endogeneity could be expected. So the test of simultaneity was done exhaustively using Hausman procedures and where confirmed, the predicted rather than observed values of affected variables were used in the respective models (Hausman 1978).

In the empirical model, eight selected villages represented eight socio-economic domains derived from the interaction of ecology (NGS, SS), population density (low, high), and market access (low, high), and they were used as main-effect factors. These domains were arranged in a hierarchical order, though they could differ with respect to some other characteristics such as presence of irrigation and major crop types, which could influence the nature and extent of intensification, but those could not be fully captured in the present analysis. Other factors included in the model are farm type (with crop farming, livestock farming and mixed farming as categories, the underlying assumption is that mixed farms were likely to be more intensively cultivated given the 'advantage' of crop–livestock integration) and animal traction use (with non-user and user as categories). In each equation a number of relevant covariates were used.

2.4.2 Results and discussion

The results of the best-fit AnCov models are presented in Table 1. Results with respect to each of the seven selected indicators of intensification are discussed below. Tests of endogeneity showed significant relationships at 10% level of significance (LOS) between the dependent and some independent variables in some equations. In these cases, as indicated earlier, predicted rather than observed values of the independent variables were used in final estimates. In general the explanatory power of the equations are reasonable but not very high. One possible reason is that some unknown important covariates were not included in the models. The covariates control for within domain variations. For example, a village classified as high or low population density will have differences among the sample farms in terms of land per capita, which in turn could have impact on an intensification indicator. Use of land/capita as a covariate captured any difference between a high and a low population density domain. However, there was no farm-specific market access data to use as a covariate, so the difference between market access domains could not be assessed as precisely as the effects of population density. Consequently, the overall explanatory power of the model was lower than it could possibly be.

Table 1. Factors influencing selected indicators of agricultural intensification and crop–livestock interaction.

Factors and covariates	Indicators						
	Land use intensity (no. of cropping cycles before fallow) Coefficient (s.e.)	Labour intensity (persondays/ha) Coefficient (s.e.)	Manure per hectare (kg/ha) Coefficient (s.e.)	Animal traction (days/ha) Coefficient (s.e.)	Chemical fertilisers per hectare (kg/ha) Coefficient (s.e.)	Tropical livestock unit per hectare (TLU/ha) Coefficient (s.e.)	Cash income from livestock/ gross income
Intercept	3.890 (2.163**)	112.37 (14.15***)	11.659 (192.8)	268.27 (34.709***)	484.685 (207.9**)	2.323 (1.152**)	0.209 (0.062***)
Factors							
Domains							
NGS LPLM	0.000	0.000	0.000	0.000	0.000	0.000	0.000
NGS HPLM	−4.891 (1.855***)	25.825 (14.294*)	−368.7 (239.816)	−6.373 (1.192***)	−502.3 (229.8**)	−0.470 (1.150)	−0.113 (0.061*)
NGS LPHM	0.805 (1.924)	0.924 (14.767)	102.9 (171.8)	−5.829 (1.255***)	−2941.6 (481.5***)	1.850 (1.211)	−0.010 (0.065)
NGS HPHM	0.564 (1.944)	12.357 (14.902)	236.8 (177.1)	−4.098 (1.275***)	470.2 (235.6**)	−1.056 (1.210)	−0.078 (0.064)
SS LPLM	7.260 (1.808***)	17.393 (13.907)	293.3 (170.6*)	−4.634 (1.226***)	1062.9 (275.2***)	−0.741 (1.145)	0.165 (0.060***)
SS LPHM	4.325 (2.067**)	−0.831 (14.374)	457.2 (181.1***)	−5.275 (1.237***)	1285.5 (296.5***)	−1.160 (1.160)	0.132 (0.062**)
SS HPLM	8.765 (1.879***)	26.328 (14.332*)	356.9 (174.9**)	−7.447 (1.180***)	−131.7 (224.8)	−0.628 (1.154)	−0.159 (0.062***)
SS HPHM	20.101 (1.965***)	23.394 (17.322)	250.6 (203.9)	−7.968 (1.210***)	−1211.8 (301.5***)	−0.212 (1.203)	0.053 (0.064)
Farm types							
Mixed farmer	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Livestock farmer	−0.587 (1.613)	−32.923 (13.453**)	120.38 (128.7)	−1.922 (1.028*)	−8690 (1238***)	7.201 (0.873***)	0.097 (0.052*)
Crop farmer	−0.150 (1.192)	−22.439 (9.141***)	−2300 (407***)	−1.380 (0.673**)	−1611 (252***)	−2.155 (0.653***)	−0.015 (0.036)
Animal traction							
Non-user	−	−	−	−	−	−	−
User	−	−	−	−	153.6 (123.8)	−0.816 (0.694)	−0.084 (0.037**)
Covariates							
Farm size/caput (ha)	2.425 (1.202**)	−71.343 (8.666***)	−257.2 (112.6**)	32>−403.522 (53.331***)	41.882 (8.787***)	−1.484 (0.723**)	−0.084 (0.039**)
Farm size/caput2 (ha)	−0.272 (0.119**)	5.671 (0.879***)	23.67 (10.77**)	34.133 (4.513***)	−	0.104 (0.072)	0.006 (0.004*)
Manure (kg/ha)	0.0006(0.000***)	−0.011 (0.002***)	−	−	−0.024 (0.047)	−	−

Chemical fertilisers (kg/ha)	0.001 (0.000***)	0.009 (0.003***)	-0.007 (0.031)	–	–	0.0000 (0.000)	0.00002 (0.000)
Land with crop legume (%)	–	–	–	–	501.11 (215.1***)	-2.271 (1.052**)	-0.086 (0.057)
Livestock (TLU/ha)	0.533 (0.223***)	13.920 (1.526***)	104.26 (49.33**)	-91.712 (12.196***)	968.3 (139.5***)	–	0.022 (0.006***)
Livestock (TLU/ha)2	-0.006 (0.004*)	-0.124 (0.025***)	26.42 (1.85***)	1.269 (0.169***)	–	–	-0.0002 (0.000*)
Crop labour (persondays/ha)	0.016 (0.006***)	–	-3.199 (0.945***)	-5.623 (0.746***)	14.180 (2.357***)	0.013 (0.004***)	-0.0003 (0.000)
Livestock labour (persondays/ha)	0.018 (0.013)	–	–	-2.368 (0.313***)	30.517 (3.496***)	-0.27 (0.008***)	0.0008 (0.000*)
Animal traction dummy (User = 1)	1.113 (1.059)	-9.958 (8.097)	110.354 (96.538)	–	–	–	–
Experience as mixed farmer (years)	0.303 (0.037***)	0.121 (0.296)	-14.447 (6.143**)	2.564 (0.337***)	-112.970 (16.209***)	-0.109 (0.023***)	0.003 (0.001***)
Land use intensity (no. of cropping cycles)	–	0.458 (0.298)	11.270 (4.881**)	–	0.013 (0.004***)	-0.090 (0.035**)	–
Other capital investments (Naira/ha)	–	–	0.007 (0.003**)	0.157 (0.021***)	–	0.00004 (0.000**)	0.0000 (0.000)
R ²	0.48	0.44	0.48	0.23	0.20	0.31	0.22
<p>Figures in bold were derived from the predicted rather than the observed values of corresponding covariates. Also, some covariates that exhibited endogeneity/high collinearity were automatically excluded from the model, e.g. manure/ha with TLU/ha as dependent variable. For covariates ***, ** and * indicate t values significant at 1%, 5% and 10% levels, respectively. For categories in factors, ***, ** and * indicate that the coefficient of that category is significantly different from the base category in the factor, based on joint univariate 0.99, 0.95 and 0.90 Bonferroni interval. NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population–low-market; LPHM = low-population–high-market; HPLM = high-population–low-market; HPHM = high-population–high-market.</p>							

However, it may be noted that agricultural intensification is at early stages in West Africa and as will be explained below, the process is taking place through various pathways, with population and market interchanging the timing and importance of their roles in the two ecozones. As a result, the number of factors and covariates that explain each indicator of intensification and the level to which they do so vary both spatially and temporally. In other words, where intensification is more advanced, its indicators would be expected to be better explained by the specified factors and covariates and more so when the hypothesised pathway for the location approximately fits the actual pathway.

2.4.2.1 Land use intensity

Theoretically, land use intensity (Table 1) would be expected to be the first indicator of intensification driven by population pressure and further enhanced by better market access. In some situations where legislation requires that continuous activities be performed on a piece of land to retain its ownership, continuous yearly cropping may be adopted as a strategy for meeting that requirement rather than as a result of pressure on land and the need to intensify its use. However, this was not the case in the study area.

The specified factors and covariates explain 48% of the variation in the land use intensity and both socio-economic domain and farm type appear to be important factors. The results of this survey indicate an average of 17 cycles of continuous cropping before a plot is put into short fallow. In the NGS and the SS, farm plots were being cultivated annually for up to 9 and 23 cycles, respectively, before being allowed to lie fallow for 1 or 2 years. Compared to the NGS LPLM domain, continuous cultivation is significantly shorter only in the NGS HPLM domain but longer in all the domains in SS, the highest being in SS LPLM and SS LPHM. In the SS HPHM in particular, farmers not only use land more continuously, they practice double or even triple cropping on some plots in a given year aided by the availability of private or public irrigation facilities. Hence land use intensity is highest in this domain than any other domain in the study area.

Crop farms cultivated land for a shorter period before putting to fallow compared to mixed farms. Although the difference is not significant, one possible reason for this is that compared to crop farms a higher percentage of mixed farms use manure and/or fertiliser (Tables 2 and 3) and they use manure at a higher rate. Among the covariates that moderated the effects of different factors on land use intensity, land–man ratio, herd size, rates of application of manure and fertilisers, crop labour and years of experience in mixed farming were significant.

Land use intensity increased as land–human population ratio increased but at very high land–human population ratios land use intensity decreased, which would be expected because of family labour shortage. At low TLU/ha, land use intensity was low and it increased with higher livestock density, indicating that when crop–livestock interaction and integration increase, land use intensity also increase. This is further evidence of the positive relationship between crop–livestock interactions and agricultural intensification through application of manure (see below). Land use intensity is higher in mixed farms and it increased with longer experience in mixed farming.

Table 2. *Proportion of farms using manure, fertiliser and animal traction by production domain and farm type.*

Production domain and farm type	Percentage (%) of farms using		
	Manure	Fertiliser	Traction
NGS LPLM	64	67	81
NGS LPHM	86	80	59
NGS HPLM	42	92	34
NGS HPHM	80	91	86
NGS (average)	66	83	63
SS LPLM	94	33	81
SS LPHM	94	41	82
SS HPLM	98	80	31
SS HPHM	83	97	21
SS (average)	93	62	54
Crop farms	76	79	53
Livestock farms	89	43	77
Mixed farms	93	65	61
All farms (Total average)	81	72	58
NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population –low-market; LPHM = low-population–high-market; HPLM = high-population–low-market, HPHM = high-population–high-market.			

Table 3. *Distribution of farms according to combination of input use by production domain and farm type.*

Production domain and farm type	Input type and combination used by farms by domain and farm type (%)							
	No manure, fertiliser or traction	Manure only	Fertiliser only	Traction only	Manure + fertiliser	Manure + traction	Fertiliser + traction	Manure + fertiliser + traction
NGS LPLM	6	5	6	6	11	16	17	33
NGS LPHM	3	12	7	0	39	5	3	31
NGS HPLM	4	1	42	1	31	1	11	8
NGS HPHM	0	0	11	2	18	7	7	55
NGS (Average)	4	4	18	2	25	7	10	30
SS LPLM	1	18	1	4	12	44	0	20
SS LPHM	0	20	0	3	16	37	3	23
SS HPLM	1	15	1	0	65	4	0	14
SS HPHM	1	0	14	0	65	1	1	17
SS (Average)	1	13	4	2	40	22	1	18
Crop farms	3	5	13	2	33	10	6	26
Livestock farms	0	15	3	4	23	38	4	14
Mixed farms	1	19	5	0	38	16	2	20
All farms (Total average)	2	9	10	2	33	15	5	23
NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population–low-market; LPHM = low-population–high-market; HPLM = high-population–low-market; HPHM = high-population–high-market.								

2.4.2.2 Labour intensity

Population pressure first induces more intensive use of land. Then, it induces higher rates of labour use to increase productivity through better land and crop management, manure and fertiliser application, caring and feeding animals (Boserup 1965; Ruthenberg 1980; Boserup 1981; Jabbar 1981; McIntire et al. 1992). Improved market access may enhance the process (Jabbar 1996). Intensification through crop–livestock integration has different implications for the crop farmer and the livestock farmer in the study area. For the livestock farmer, intensification is expected to lead to smaller herd sizes and more intensive management involving crop residue gathering and cut-and-carry feeding. Consequently, labour per TLU is expected to increase. The reverse is the case for crop farmers whose stock sizes are still small and probably need to increase in order to optimise their land and labour use as well as crop residue utilisation. In their case, labour per TLU is expected to decrease as the herd size increases. These apparently different uses of farm labour for livestock and for crop productions were first tried separately in the equations but the results were not as distinct as when aggregated into total person-days of labour per hectare.

The specified factors and covariates explained 44% of the variation in labour use intensity. Compared to the LPLM domain in NGS, only the HPLM domains in both the NGS and SS applied labour at significantly higher rates. Compared to mixed farms, crop and livestock farms applied labour at significantly lower rates, which might be expected. The signs and coefficients of the covariates confirm that farms with smaller farm plots increased their labour use intensity. Higher application rates for fertilisers led to higher labour use but the reverse was the case for higher levels of manure application per hectare. This was the case because kraaling animals overnight on given portions of the farm, which is a major way of applying manure, does not require extra labour unlike the application of fertilisers which have to be done using human labour. The results also show that initial increases in herd size required extra labour but this reduced as herd sizes got larger, as should be expected since the relationship between herding labour and herd size is not linear but declining.

2.4.2.3 Rate of application of manure per hectare

This indicator portrays both input intensification and crop–livestock interaction (Table 1) (McIntire et al. 1992; Jabbar 1996). The factors and covariates explained 48% of the variation in manure application. The mean application rate for manure was 4800 kg/ha and 81% of the farmers applied manure to their fields (Table 2). There was no significant difference in manure application rates among the domains within the NGS. All the high population domains in SS applied significantly higher rates than the base domain (NGS LPLM), with the exception of the SS HPHM. In the SS, manure and fertilisers are used as complements rather than as substitute. It is therefore not so surprising that with access to fertilisers, they could afford the comparatively lower levels of manure per hectare. With this exception, a gradient of increasing rates of application of manure exists in the SS as one moves toward higher population and higher market access situations.

Compared to mixed farms, livestock farmers applied significantly higher rates of manure and crop farms applied significantly lower rates, which would be expected. Livestock farms had more manure in relation to the available land, so could apply at higher rates while mixed farms used manure mainly from own sources and through various contracts and exchanges with livestock farmers, hence these differences (Table 4).

Several covariates in the model acted as significant modifiers. As farm size decreased more manure was applied per hectare. Manure application per hectare was endogenous with TLU/ha. Thus the predicted values of TLU/ha were used in this particular case. The result still showed, as expected, that owning more cattle led to higher rates of manure application. Manure application rate also increased with cycles of continuous cropping, further reinforcing the fact that the contributions of livestock to intensification takes place through manure to improve soil fertility when land use intensity is increased. As also expected, manure application rates or intensification increased when capital investments in farm equipment, e.g. traction implements, spraying equipment increased.

2.4.2.4 Animal traction days used per hectare

Use of animal traction portrays both input intensification and crop–livestock interaction and signifies an important stage in the process of intensification (Pingali et al. 1987; McIntire et al. 1992). Fifty-eight per cent of the sample used traction (Table 1). A higher proportion of NGS farms and a higher proportion of livestock farms used traction from either own or purchased sources (Table 4, also see Table 6). The factors and covariates in the model explain 23% of the variation in the use of animal traction. Compared to the LPLM domain in NGS, all the other domains used significantly lower number of days of animal traction. Since traction is supposed to replace human labour, lower traction use in high population density areas may not be unrealistic. But in better market access domains, higher traction use would be normally expected. The somewhat opposite result in this study may be explained by the phenomenon of urban–rural migration in the study area where youths migrate to urban and peri-urban areas for better jobs but are forced to work as cheap farm labour during their initial period of search for other employment. Consequently, areas with better market access in peri-urban areas stick to human labour for farm operations while low-population–low-market access

domains, being labour scarce due to migration, may be forced to use traction sooner than the high-population–high-market access domains.

Table 4. *Distribution of farms according to sources of manure by production domain and farm type.*

Production domain and farm type	Percentage (%) of farms by sources of manure, domain and farm type			
	None	Own	Purchase	Own + purchase
NGS LPLM	36	61	0	3
NGS LPHM	14	83	0	3
NGS HPLM	58	36	3	3
NGS HPHM	20	68	0	12
NGS (average)	34	60	1	5
SS LPLM	6	77	1	16
SS LPHM	6	66	0	28
SS HPLM	2	73	5	20
SS HPHM	17	61	3	19
SS (average)	7	70	2	21
Crop farms	25	60	2	13
Livestock farms	11	84	1	4
Mixed farms	7	69	1	23
All farms (total average)	19	65	2	14
NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population-low-market; LPHM = low-population-high-market; HPLM = high-population-low-market; HPHM = high-population-high-market.				

Compared to mixed farms, crop farms and livestock farms applied significantly less traction days. The fact that livestock farmers applied significantly less animal traction than mixed farmers should not be surprising because most livestock farmers have small farm size in relation to available labour, so use hand tools for land preparation. Several covariates in the model modify animal traction at highly significant levels. Traction use increased with land per capita, experience in mixed farming and special capital investments.

2.4.2.5 Rate of application of fertiliser per hectare

Manure and fertilisers may be complements or substitutes depending on the stage of intensification and crop–livestock interaction (McIntire et al. 1992; Smith et al. 1993; Jabbar 1996). Results in Table 1 indicate that manure and fertilisers were used as substitutes in the NGS but as complements in the SS. Eighty-one per cent of sample farms used manure, 72% used fertilisers. A higher proportion of farms in SS applied manure than those in NGS, and more mixed farms applied manure than the other two farm types (Table 4). However, a higher proportion of NGS farms applied fertiliser than those in SS even though application rates were higher in the SS (205 kg/ha) than in the NGS (175 kg/ha).

The model explained only 20% of the variation in the quantity applied per hectare. This low explanatory power may be partly attributed to the definition of variable. The rate has been calculated assuming that all plots of a farm have been fertilised while in reality fertiliser is applied selectively to specific crops. By traditional practice in the study area, fertilisers are applied to cereals (maize, sorghum and millet) but not legume crops (mainly groundnuts and cowpea). A cropping pattern of repeated alternating (1:1) rows of cereal:legume are common in the savannah zones (Tarawali et al. 2000). However, an increasing number of farmers in the area are adopting new cowpea varieties and this group—not considered as a special group in this study—usually applied fertilisers to cowpea. Moreover, a farmer would typically cultivate a number of plots in different locations, which make up the total cultivated farms for that season. We obtained information on the actual quantity of fertilisers applied for the season studied but not crop specific plot level application. Where a farmer chose not to apply fertilisers to all plots, measurement errors were introduced into the variable that could have led to a loss in its explanatory power.

Among the covariates, the explained part indicates that the farm size, the percentage of farm with legume crop, the number of TLU per hectare, labour use intensity and land use intensity were significant modifiers. Fertiliser application rate increased with higher labour intensity. The positive relationship between fertiliser and the proportion of farm under legume crops is as a result of the use of fertilisers in growing new cowpea varieties, which are increasingly being adopted in the study area (Table 5).

Table 5. *Distribution of farms according to sources of draft power by production domain and farm type.*

Production domain and farm type	Percentage (%) of farms according to source of draft power by production domain and farm type		
	None	Own	Hired
NGS LPLM	19	41	40
NGS LPHM	41	37	22
NGS HPLM	66	18	16
NGS HPHM	14	38	48
NGS (average)	37	32	31
SS LPLM	19	37	44
SS LPHM	18	52	30
SS HPLM	69	21	10
SS HPHM	79	4	17
SS (average)	46	29	25
Crop farms	47	25	28
Livestock farms	23	42	35
Mixed farms	39	38	23
All farms	42	30	28
NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population- low-market; LPHM = low-population-high-market; HPLM = high-population- low-market; HPHM = high-population-high-market.			

2.4.2.6 Number of tropical livestock units per hectare

Mixed farming is emerging in the region in two ways:

- pastoralists with large herds are becoming agropastoralists and then mixed farmers and in the process decreasing their herd sizes
- crop farmers are adopting a small number of livestock to begin with and increasing herd size with experience (Jabbar 1996).

Both population pressure and market access would be expected to expedite this process of convergence. The specified factors and covariates explained 31% of the variation in number of TLUs per hectare (Table 1). Compared with the LPLM domain in NGS, all the other domains have no significant difference. As implied in the stratification of the sample by farm types, livestock farmers had significantly higher TLU per hectare than mixed farmers and crop farmers.

Animal traction use did not have any significant influence on animal density. As already explained, livestock farmers who have higher density of livestock per unit land have small sized farms where hand tools are sufficient. Among the covariates, land per capita, labour use, experience in mixed farming and capital investments acted as significant moderators. Animal density decreased with farm size, higher proportion of legume crops on farms, livestock labour intensity, land use intensity, and increased with capital investment, crop labour intensity and experience as mixed farmer. An increase in crop labour could be seen to lead to some increase in crop and residue yields and, therefore, an increase in the ability of each hectare of farmland to support additional TLUs.

2.4.2.7 Livestock cash income in gross revenue

Intensification driven by market forces is expected to lead to an increased cash income from crops and livestock but the share of crop and livestock would be expected to vary depending on the type of farm and where they are located. Among several options to define this dependent variable, the best fit was obtained for livestock cash income as a ratio of gross revenue (Table 1) and the model explained 22% of the variation in this indicator. Compared with the LPLM domain in NGS, LPLM in NGS and HPLM domains in SS had significantly lower cash income from livestock while LPHM domain in SS had significantly higher cash income ratios from livestock.

Normally, a higher share of livestock in cash income would be expected as one moves toward high market access situations. Ndubuisi et al. (1998) and Okike (2000) showed that income from livestock and its products account for 12.2% of gross income in the area, the highest (21.8%) being in the HPLM domains and lowest (4.2%) in the HPHM. They further showed that this 'decline' in HPHM domain happened without a decline in the absolute income of each household from livestock and its products. It means that the widening of the gap

in the contributions of crop and livestock to household income is more due to higher returns from higher value crops rather than due to a decline in returns from livestock and its products. The challenge is to match high value crops in the farming systems with high performance animals.

Boosting income from the livestock component, as intensification increase is a desirable goal as it retains farmers' interest in both the crop and livestock components and encourages the implied sustainable use of natural resources. This increase will come more easily from policies that improve the output of livestock products, e.g. milk—which is in high demand and must be sold quickly, rather than from policies that seek to encourage sale of live animals, which perform several functions on farm—manure, store of value, security.

Crop farmers had a significantly lower ratio of livestock cash income compared to mixed farmers. Among the covariates, herd size and experience as mixed farmer acted as significant modifiers: livestock cash income ratio increased with herd size and experience in mixed farming.

2.5 Summary

This chapter presented a hypothesis on agricultural intensification and used primary data from the savannah zones of Nigeria to statistically test the hypothesis. From the results, we can broadly conclude that agricultural intensification is taking place in the NGS and SS zones of West Africa. Specifically:

- ecology, population density and market access and their interactions are the most important drivers of this process in the region
- the degree of intensification is higher in the SS than in the NGS and this occurs principally through increased intensity in the use of land, manure, and labour followed by increased intensity in the use of commercial inputs and cash income orientation
- decreasing herd sizes among livestock farming households and increasing herd sizes among originally crop farming households indicate that greater crop–livestock interaction and integration occur as intensification increases; in fact, it points to the emergence of mixed farming enterprises owned and managed by single farming households rather than the interaction (without integration) of separate crop and livestock farming households induced mostly by the benefits of manure, crop residue and animal traction.

These results imply that policies that substantially improve market access for products and inputs will facilitate a process of agricultural intensification in which livestock are integrated with crop farming. High value livestock production must be promoted to balance the contribution of crop and livestock components to the farm unit, to retain the interest of farmers in crop–livestock integration and sustainable farming. Facilitating the emergence of such mixed farms and promoting their sustenance will also reduce conflicts that sometimes occur between pastoralists and crop farmers over access to feed resources and crop damage.

3 Factors affecting farm-specific economic efficiency: Application of frontier production function

[3.1 The theoretical model](#)

[3.2 Specification of the empirical model and definition of variables](#)

[3.3 Results and discussion](#)

[3.3.1 Differences in economic efficiency among classes of farms](#)

[3.3.2 Productivity of farm inputs](#)

[3.3.3 Economic inefficiency effects](#)

[3.3.4 Characteristics of most efficient and least efficient farms](#)

[3.4 Summary](#)

Questions may be asked about whether the forces that drive intensification as explained in the previous chapter also contribute to improved efficiency in resource use so that there are differences in the levels of efficiency among different farms. If so, which factors contribute to improved efficiency? Why and how? This chapter will deal with these questions.

3.1 The theoretical model

The pitfalls of measuring average efficiency of a sample of farms have been mentioned in the introductory chapter. Farrel (1957) distinguished between technical and allocative efficiency and this kindled interest in the measurement of economic efficiency leading to the development of a variety of ways of accounting for more than one factor of production in the production process. Among the various econometric methods that evolved, stochastic frontier functions and data envelopment analysis (DEA) are currently in the forefront. In analysing farm level data where measurement error, some missing information, weather etc. are likely to play a significant role, the stochastic frontier method is recommended (Coelli 1995).

Early frontier production functions that followed Farrel (1957) were deterministic, in that they assumed a parametric form of the production function along a strict one-sided error term (Schmidt 1976). Such forms take no account of the possible influence of measurement errors and other causes of distortion upon the shape and positioning of the estimated frontier, since all observed deviations from the estimated frontier are assumed to be the result of technical inefficiency. These problems were subsequently addressed to open the way for the numerous adaptations that represent the stochastic frontier function of the present day (Aigner et al. 1977; Coelli 1995).

Currently, the stochastic frontier production function is basically specified as a composed error model of the general form:

$$\ln(Y_i) = F(X_i; \beta) + \varepsilon_i \quad i = 1, 2, \dots, N \quad (2)$$

where Y is the output of the i^{th} farm; X is the vector of input quantities used by the i^{th} farm; b

is a vector of unknown parameters to be estimated; $F(\cdot)$ represents an appropriate function, (e.g. Cobb-Douglas, transcendental-logarithmic etc.), and e_i the error term, equals $V_i - u_i$. The term u_i is a non-negative variable representing inefficiency in production relative to the stochastic frontier. The term v_i is a symmetric error, which accounts for random variations in output due to factors beyond the control of the farmer, e.g. weather and disease outbreak, and it is assumed to be independently and identically distributed as $N(0, \sigma_v^2)$. The distribution of u_i is also assumed to be independent and identical as $|N(0, \sigma_u^2)|$ which could be half-normal at zero mean, truncated half-normal (at mean m), and based on conditional expectation of the exponential $(-u)$. Greene (1990) also offered a two-parameter gamma distribution model. Jondrow et al. (1982) and Mubarik and Flinn (1989) specified a method for decomposing the error term e into u and v using the conditional distribution of u given e . Finally, the stochastic frontier equation irrespective of its functional form is usually estimated using the Maximum Likelihood Estimation (MLE) technique.

In some studies, the efficiency indices obtained for individual farms were subsequently regressed in a second stage against some socio-economic variables, e.g. education level of farmer, age of farmer, farm size etc. to estimate the contributions of these variables to inefficiency (Mubarik and Flinn 1989; Deb and Hossain 1995; Parikh et al. 1995; Coelli and Battese 1996). However, Kumbhakar et al. (1991) and Reifschneider and Stevenson (1991) noted a significant problem with this two stage approach, i.e. the assumption of independent and identical distribution of the inefficiency effects is violated in the second stage when they are made to be a function of a number of farm-specific factors with non-identical distribution. The above authors specify stochastic frontier models in which the inefficiency effects are made an explicit function of the farm-specific factors, and all parameters are estimated in a single stage MLE procedure as in the computer software—FRONTIER version 4.1 (Coelli 1994)—that has been used for this study.

3.2 Specification of the empirical model and definition of variables

The model employed for the stochastic production function analyses of individual farm economic efficiencies in this study is in the form of the Coelli and Battese (1996) inefficiency model. However, the effects of inputs on productivity in the various socio-economic domains were explicitly incorporated in the production function using fixed-effects methodology where each stratum has a dummy variable measuring the effect in the specific domain (Hoch 1958). This procedure avoids the problem of omitted variables and the dummies can be interpreted as a measure of technical efficiency since a link between production frontier and the fixed effects is thus established (Hoch 1976). With the above slight modifications, the final models were derived by, first, fitting ordinary least squares (OLS) models experimentally before eventually estimating by maximum likelihood methods. This procedure also alerted us if econometric problems, e.g. endogeneity and multicollinearity, existed. The estimated production function was of the form:

$$\ln(Y_i) = \sum \phi_j D_j + \sum \beta_j \ln(X_{ij}) + v_i - u_i \quad (3)$$

where D_j are intercept dummies; the subscript i refers to the i^{th} farmer; \ln is the natural logarithm and Y_i is the total value of farm output of i^{th} the farmer in Naira; x_{ij} are input variables.

The b-coefficients in equations 2 and 3 are unknown parameters to be estimated along with the variance parameters, which are expressed in terms of:

$$\sigma_{\epsilon}^2 = \sigma_v^2 + \sigma^2 \quad (4)$$

$$\gamma = \sigma^2 / \sigma_{\epsilon}^2 \quad (5)$$

where the γ -parameter has value between zero and one. The technical efficiency of a farmer is defined as the ratio of the observed output to the frontier output that could be produced by a farm operating at 100% efficiency, in which the inefficiency is zero. When the dependent variable is expressed in log, (Battese and Coelli 1992; Battese and Coelli 1993) have shown that this is determined mathematically as:

$$TE_i = \exp(-u_i) \quad (6)$$

The above transformation constrains the technical efficiency of each farmer to values between zero and one and this is related in inverse proportion to the inefficiency effect. It may be noted that the production function above does not depict a purely technical relationship between inputs and outputs for the mere reason that input prices and expected product prices varied across the study area and influenced farmers' input use and production decisions. With the underlying influence of prices, efficient combination of input is no longer a purely technical decision but also relies on economic judgment. Therefore, we subsequently and more appropriately refer to the results of the frontier function in terms of economic efficiency rather than only technical efficiency (Heertje 1977).

The v_i s are assumed to be identically and independently distributed random errors, having $N(0, \sigma_v^2)$ distribution; and the u_s s are non-negative random variables, called technical inefficiency effects, associated with the technical inefficiency of production of the respondent farmers. The Coelli and Battese (1996) inefficiency model assumes that the inefficiency effects are independently distributed and u_s arises by truncation (at zero) of the normal distribution with mean, m_{it} and variance, s_2 where m_{it} is defined by:

$$u_i = \delta_1 Z_{1i} + \delta_2 Z_{2i} + \dots + \delta_n Z_{ni} \quad (7)$$

where Z s represent factors contributing to inefficiency. In the study, the age of farmer (years), land use intensity (number of years of continuously cropping a farm plot), livestock owned (TLU), obtaining credit for farming (1 = yes, 0 = no), and belonging to farmers' co-operative society (1 = yes, 0 = no) were considered as possible factors contributing to inefficiency.

Intercept dummies have been used to measure technical efficiency differences across eight domains, three farm types, users and non-users of fertilisers and animal traction.

Some of the farms did not use animal traction and some did at varying but not so widely differing rates, so a dummy was incorporated into the production function to determine whether such input use decisions led to significant differences in efficiency between users and non-users of traction.

The input variables used in the model are farm size in hectares, labour in persondays, chemical fertilisers used in kilograms, and other costs to cover expenditure on seeds, crop residue, animal traction implements and other miscellaneous costs. Eighty-one per cent of the farms used chemical fertilisers but since $\ln 0$ is negative, non-users were credited with applying a kilogram of chemical fertilisers to their fields to allow the log-transformed values to

be non-negative. Seventy-two per cent of the farms applied manure at highly varying rates and it was initially defined as a continuous variable giving a negligible positive value to non-users but the estimated coefficient had high standard error, hence not statistically significant. This could be explained in terms of various factors related to the quantity and application method of manure, which could not all be controlled for across the study area. The manure response of crops is related to:

- length of time of storage: long composting results in loss of nitrogen, carbon, phosphate and other soil nutrients to volatilisation, bio-oxidation, nitrous oxide emission and leaching (Eghball et al. 1997)
- season of production: dietary crude protein levels and degradability influence nitrogen excretion in urine and faeces and both are higher in the wet season (Reynolds and de Leeuw 1995; Schlecht et al. 1995)
- manure and chemical fertiliser, and manure and urine interactions (Anon 1998)
- type of soil to which it is applied as related to carbon releases and carbon–nitrogen exchanges
- amount of rainfall in the year of application: high amounts of rainfall could lead to leaching while too little rain could lead to very slow nitrogen releases and adverse moisture competition between crop and manure dry matter
- timing of application, both in terms of period and frequency in order to synchronise N release and availability in the soil with demand for, and uptake by, crop plants (Murwira et al. 1995; Schlecht et al. 1998)
- cultivation of dual-purpose legumes by mixed farms also contributes to production of better quality manure (Inaizumi et al. 1999)

In the study areas, manure is usually collected from livestock kraals around the homestead and transported to farms in 50 kg bags, on donkeys or ox-drawn carts, just prior to the planting season. In recent times, manure is also purchased from city abattoirs at ₦ 700 (US\$ 8.2)/t and transported by truck to farms. In most cases, manure is applied to the same field only in alternate years, i.e. once in two years. Therefore, considerable time period elapses between collection (composting) and application, which could lead to C, N and P losses already outlined.

It was practically impossible to control for the effects of differences in soil quality, rainfall, daily temperature and manure quality to assess the effect of manure quantity on output, hence the estimated coefficient probably did not capture the true effect of manure. Therefore, it was decided to use manure as a binary variable (user = 1, 0 otherwise) in the model. The result clearly indicates that users of manure operate at a higher level of economic efficiency than non-users (see below).

3.3 Results and discussion

This part of the paper is presented in four sections to account for i) differences in economic efficiency among the various socio-economic production domains, ii) productivity of input factors, iii) inefficiency effects, and iv) characteristics of frontier and poor performing farms.

3.3.1 Differences in economic efficiency among classes of farms

The estimated statistics and parameters of the model are shown in Table 6. The values of the likelihood ratio (LR), sigma-square (s^2) and gamma (g) in Table 6 indicate that the model has a good fit and that inefficiency effects of a stochastic nature exist. The results show highly significant differences in the parameters across the socio-economic domains and also between users and non-users of animal traction and users and non-users of manure. For the socio-economic domains, economic efficiency varied and increased substantially from the

NGS LPHM, which is the base domain, through the NGS HPLM to the NGS HPHM domains. Even though the SS LPLM and the SS LPHM domains operated at lower economic efficiency levels relative to the NGS LPLM domain, a sequence of increasing economic efficiency can be traced from SS LPLM domain—the lowest—to SS HPHM domain—the highest. Therefore, within each agro-ecological zone, these results show higher economic efficiency with increased population pressure and market access. Such a relationship has also been shown in Chapter 2 to exist between these factors and agricultural intensification.

Table 6. *Maximum likelihood estimates for parameters of the stochastic frontier production function and economic efficiency of farmers in the savannah zones of northern Nigeria.*

Dummies in the production function	Coefficient (s.e)
Intercept ¹	6.825*** (0.495)
Domains	
NGS LPLM	0
NGS LPHM	0.492** (0.228)
NGS HPLM	0.624*** (0.224)
NGS HPHM	0.768*** (0.243)
SS LPLM	−0.607** (0.228)
SS LPHM	−0.450* (0.232)
SS HPLM	0.804*** (0.237)
SS HPHM	0.895*** (0.254)
Farm Type	
Crop farms	0
Livestock farms	0.219 (0.162)
Mixed farms	−0.099 (0.139)
Animal traction use	
User farms	0.135*** (0.125)
Manure	
User farms	0.304*** (0.128)
Variables in the production function	
Farm size (ha)	0.192*** (0.072)
Labour (persondays)	0.220*** (0.047)
Fertilisers (kg)	0.163*** (0.055)
Other costs (₦) ²	0.182* (0.118)
Inefficiency effects	
Age of farmer (years)	0.045*** (0.013)
Land use intensity (continuous cropping years)	−0.025** (0.011)
TLU owned	−0.015*** (0.002)
Credit dummy	0.899*** (0.281)
Co-operative society dummy	−0.482*** (0.183)
Other parameters	
Delta 0 (d ₀)	−1.810** (0.814)
$s_s^2 = s_v^2 + s^2$	1.387*** (0.089)
$g = s_s^2 / s^2$	0.056*** (0.012)

Log likelihood function	−885.4
Average economic efficiency (%)	60.28
Levene statistic ³ for domains (sig.)	1.305 (0.245)
ANOVA between groups	$F_{7, 551} = 5.153 (0.000)$
<p>1. The reported intercept is based on NGS LPLM domain, crop farms and non-users of animal traction.</p> <p>***, ** and * show statistical significance at the 1%, 5% and 10% levels, respectively.</p> <p>2. US\$ 1 = ₦ 85 at the time of the field survey.</p> <p>3. A test of homogeneity of variance. It is insignificant meaning equality of variance within sample. NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population–low-market; LPHM = low-population–high-market; HPLM = high-population–low-market; HPHM = high-population–high-market.</p>	

The SS HPHM and SS HPLM domains have the highest level of economic efficiency. In these domains, land and labour and manure use intensities are among the highest (see Chapter 2). Livestock management is also more intensive than elsewhere and the grazing of all crop residues is done on the farm, particularly in the SS HPHM domain. This may provide additional benefits from urine in concert with manure leading to better quality manure to the soil (Jahnke 1982; Anon 1998) and considerable savings in resources required first to gather and transport crop residues to the homestead, and later to gather and transport manure back to the farm. However, the degree of crop–livestock integration is still low in the study area and when this will become the dominant system, relative input intensity and relative prices may also change in such a manner that higher level efficiency in such systems might be expected compared to other systems.

The users of animal traction have reached a significantly higher production frontier over non-users. This is an expected outcome and is in line with the evolutionary pathway for agricultural energy intensification (Jabbar 1996).

The positive relationship between agricultural intensification and economic efficiency, and the significant productivity of animal traction as a substitute for human labour reinforce each other and suggest the potential of a higher level of adoption of animal traction technology than is currently the case in most of West Africa. Between the NGS and the SS, the same animal traction equipment designs are promoted for the relatively lighter soils of the SS and the heavier soils of the NGS. More biophysically responsive approaches are required to reduce the implicit inefficiencies of inappropriate engineering designs in order to make animal traction more productive and more attractive to farmers. In peri-urban areas, animal traction also faces the challenge from the availability of cheap labour made possible by the large number of able-bodied youths who migrate from rural to urban and peri-urban areas and are constrained to sell their unskilled labour during their initial period of search for employment. Other challenges faced by farmers' use of animal traction include short growing seasons and animal-tending costs implied in the opportunity cost of labour and capital during off-season (Ehui and Polson 1992). Animal traction technology become somewhat profitable and attractive partly because of the revenue obtained when retired work bulls are fattened and sold.

Overall, the results of this chapter indicate that differences in economic efficiency exist especially among the socio-economic domains, between users and non-users of manure and between users and non-users of traction. It is discernible that a gradient of increasing economic efficiency could be traced, within agro-ecological zones, from LPLM domains through to HPHM domains, making it conceptually plausible that the agricultural productivity constraints of the NGS and SS of West Africa could also be addressed in a similarly graduated manner. This may imply improving economic efficiency in LPLM domains—where efficiency is low—and introducing new technological packages in the HPHM domains where economic efficiency is sufficiently high to accommodate further technical change.

3.3.2 Productivity of farm inputs

The estimated coefficients of all the input variables in the production function have positive signs as expected (Table 6). In general, the results show decreasing returns to scale in farm operations in the sample areas, given that the sum of the gross revenue elasticities of the inputs in the production function is significantly less than unity. An increase in farm size by 10% could result in increase in gross output by about 2% while a similar increase in persondays of labour is expected to result in an increase in gross output by 2.2%. Also, application of chemical fertiliser, and expenditure on seeds, pesticides, herbicides, crop residues and other miscellaneous inputs, i.e. other costs, led to significant increases in productivity. Higher expenditure on seeds resulting from buying higher quality seeds, combined with expenditure on pesticides and herbicides is an example that confirms the notion that higher input use could lead to higher productivity resulting from positive interactions among inputs, especially when they are of improved quality.

3.3.3 Economic inefficiency effects

Causes of inefficiency in farms were determined with the production frontier in a single-stage maximum likelihood estimate. The results, also presented in Table 6, indicate that inefficiency exists among farms in the sample and is high among aging farmers and those that received credit. Owning more livestock, higher land use intensity, and belonging to farmers' co-operative societies reduce inefficiency. In West Africa, farming still requires a high level of physical fitness, especially for tilling the soil. In the light of that, the result that aging increases inefficiency is not surprising. What is surprising is that receiving credit contributed to farmers' economic inefficiency. This could be the result of disbursement of credit in cash rather than in kind and loan misapplication engendered by resource-poverty. It is difficult to argue against the role of credit in agriculture, especially among resource-poor farmers, since any misapplication may have been directed towards other livelihood strategies and consumption goods that improve overall household well-being and indirectly affects current productivity (John Pender, International Food Policy Research Institute (IFPRI), 2033 K Street, NW, Washington DC, 20006, USA, personal communication).

The reduction of inefficiency effects through farmers belonging to co-operative societies is linked to co-operatives being a source of good quality inputs, information and organised marketing of products—especially dairy products. Higher land use intensity also reduced economic inefficiency effects as should be expected with more complete utilisation of resources. It may also be that when land is under fallow it provides a source of forage for livestock, which, in turn, return nutrients to it, in situ. In continuous cropping, the manure collected at homestead especially by mixed farms is returned to the soil. Since more intensive land use through continuous cropping appears to be more beneficial through the use of biomass as livestock feed, either in situ or as crop residue, and if more biomass is available from a plot when cropped than when fallow, then more manure is likely to be returned to it from the homestead. Thus incremental net benefits may accrue to both crop and livestock enterprises during continuous cropping. This may be another reason, in addition to population pressure, for the increasing number of cycles of continuous cropping (17 cycles on average) in the savannah zones of West Africa.

3.3.4 Characteristics of most efficient and least efficient farms

The frequency distribution and probability histogram rating the economic efficiency of the 559 farms is presented in Figure 2. The mean economic efficiency for the sample is 60.3%. Two farms were less than 20% efficient while 7 farms were more than 90% efficient. There was only one frontier (100% efficient) farm. The implicit frequency curve is mesokurtic with no

significant suggestion of skewness.

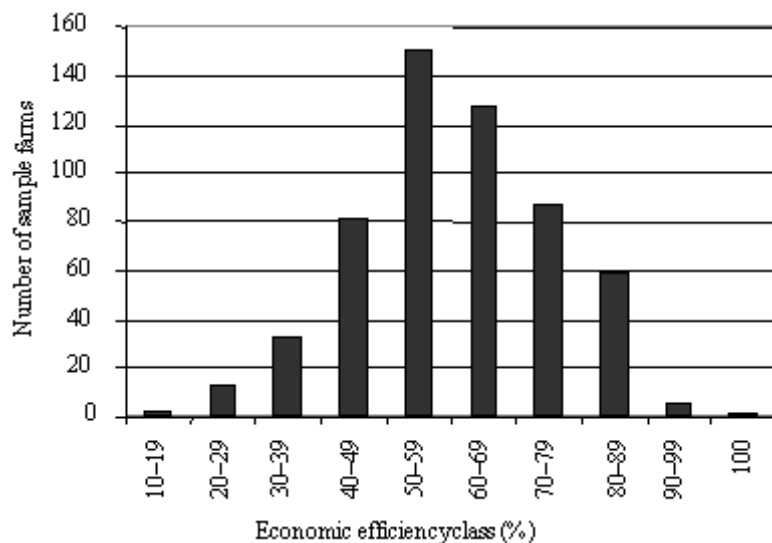


Figure 2. *Distribution of the economic efficiency of farms in the savannah zones of Nigeria.*

Examining the frontier farms and worst performing farms is of obvious policy interest. Taking advantage of the farm-specific economic efficiency output of stochastic frontier programmes, farms were distributed into the top and bottom 10% and were characterised (Table 7). Constructing a thick frontier from up to 10% of the top performing farms may dilute the qualities of the farm that operated at 100% economic efficiency but it reduces the probability of recommending the characteristics of frontier farms that may be considered too optimistic. Results from a thick frontier are more practical and applicable to a wider array of farms. For similar reasons, rather than taking the lowest performing farm, a bottom 10% was also used for poor performing farms (Table 8).

Table 7. *Productivity and selected farm characteristics of least economically efficient and most economically efficient farms.*

Indicators	Least efficient farms (n= 56) ²	All farms (n = 559)	Most efficient farms (n =56) ²	ANOVA ³ (sig.)
Economic efficiency (%)	33	60	85	0
Gross revenue (₦/ha) ¹	12,676	24,834	81,307	0.043
Farm size (ha)	6.5	5.8	4.4	0.092
Continuous cropping (years)	13	14	17	0.019
Fertiliser used (kg/ha)	103	192	94	0.766
Manure (kg/ha)	122	479	1,313	0.024
Livestock labour (man days/TLU)	20	11	14	0.544
Crop labour (man days/ha)	88	78	80	0.663
Animal traction used (days)	7	9	20	0.148
Age of	55	44	39	0

respondent				
TLU owned	4.4	6.3	22.8	0
Expenditure on crop residue (₦)	229	698	1,320	0.027
Other costs(₦/ha)	2,980	3,300	5,803	0.416
1. US\$ 1 = ₦ 85 at the time of the field survey. 2. Equals 10% of the sample. 3. Level of significance of ANOVA between least efficient and most efficient farms.				

Major characteristics of the most efficient farms that differentiate them in a statistically significant manner from the least efficient farms are:

- higher gross revenue per hectare
- smaller farm size
- higher land use intensity (longer years of continuous cropping)
- higher quantity of manure applied per hectare
- younger age of farmers
- higher number of livestock (TLU) owned
- higher cash expenditure on crop residue.

Table 8. *Distribution of the most efficient and least efficient farms by socio-economic domains, agro-ecological zones and farm types.*

Production domain or farm type	Total sample (%)	Least efficient farms (%)	Most efficient farms (%)
NGS LPLM	11	23	12
NGS LPHM	11	14	5
NGS HPLM	13	11	2
NGS HPHM	10	11	2
NGS (total)	45	59	21
SS LPLM	15	11	25
SS LPHM	13	5	25
SS HPLM	14	18	9
SS HPHM	13	7	20
SS (total)	55	41	79
Crop farms	45	50	14
Livestock farms	14	14	34
Mixed farms	41	36	52
NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population-low-market; LPHM = low-population-high-market; HPLM = high-population-low-market; HPHM = high-population-high-market.			

In Table 8, the distribution of the least efficient and most efficient farms is shown according to socio-economic domains, ecological zones and farm types. The table shows, for example, that the NGS LPLM domain, which contained 11% of the sample, contributed as much as 23% to least efficient farms and 12% to most efficient farms. By contrast, the SS HPHM domain that made up 13% of the sample had only 7% of its farms in the least efficient group and as high as 20% in the most efficient group. Linking this result to that in section 3.3.1 shows that the NGS LPLM not only operated at the lowest level of economic efficiency compared to other domains but it also had a proportionately higher number of inefficient farms. By the same

token, SS HPHM not only operated at the highest level of economic efficiency, for domains, but it also had proportionately higher number of frontier farms. So, the ranking of the socio-economic domains remains consistent between both yardsticks.

Livestock farms had a higher starting point for economic efficiency than crop farms and mixed farms (see section 3.1). The distribution of least efficient and most efficient farms shows that mixed farms had proportionately fewer inefficient farms and proportionately higher efficient farms. It is followed by livestock farms, which contributed exactly its own quota to inefficient farms but had a higher representation among most efficient farms. Following the same standards, crop farms were the least efficient of the farm types since they contributed more than proportionately to inefficient farms and by far lower to efficient farms (Table 8). Thus, mixed farming whose operations exemplify greater crop–livestock interactions and integration also led to greater economic efficiency. Farms in the SS can similarly be seen to have been ahead of those in the NGS in economic efficiency.

3.4 Summary

The stochastic frontier production function technique was used to examine the economic efficiency of 559 farms in West Africa along i) two agro-ecological zones, namely northern Guinea savannah and Sudan savannah; ii) four socio-economic strata made up of low-population–low-market, low-population–high-market, high-population–low-market and high-population–high-market domains in each of the two zones; and iii) three farm types–crop, livestock and mixed. The study analysed differentials in economic efficiency of the farms, determined input factor productivity, identified inefficiency effects and characterised the farms according to their economic efficiency levels.

The results demonstrate that differences in economic efficiency of farms, in the northern Guinea and Sudan savannahs of West Africa occur in a pattern related to their biophysical and socio-economic circumstances. This gradient of economic efficiency is particularly vivid in the analysis by the socio-economic domains and could be traced from the LPLM domains to the HPHM of each of the agro-ecological zones, in an increasing order. Overall, farms in the SS also operated at a higher level of economic efficiency than those in the NGS. This is the same order in which agricultural intensification is occurring in the same region. It can thus be concluded that intensification leads to higher economic efficiency especially when an increase in the use of one input interacts synergistically with improved quality or increased quantity of other inputs. It can also be concluded that greater crop–livestock interactions and integration in farms lead to higher economic efficiency.

Following the hierarchy of efficiency levels revealed by the results of this study, it could be speculated that LPLM domains need more education and training to improve their farming skills than they do need new technologies, as they have not yet attained sufficiently high economic efficiency in managing existing resources as to cope easily with frontier-shifting innovations. By contrast, the HPHM domains, especially in the SS seem ready for fresh ideas as they are considered capable of coping with both technical change and technical efficiency improvement, simultaneously.

Important issues are raised about the quality and quantity of manure in farming systems. These attributes were not studied directly but the results of this study suggest that the time lapses between the collection of manure and its application to farms at the beginning of the planting season is so long that the loss of mass, nitrogen, carbon and phosphate is inevitable. As such, rather than a single massive application at the beginning of the planting season, the use of manure should be more frequent and better timed to optimise the utilisation of released nitrogen by crops (Murwira et al. 1995). In the SS where temperatures are higher and relative humidity is low, there is the need to store manure under shade to lower nitrogen loss and prevent desiccation. In the NGS, leaching (run off) of phosphate is likely to be the most

important source of loss of quality. Fortunately, loss of phosphate during storage is very low and, therefore, manure is still able to contribute substantially to soil phosphate even after long storage (Eghball et al. 1997; Powell and Valentin 1998). Such developments are likely to occur along with crop–livestock integration but extension education at early stage of crop–livestock interaction through on-farm paddocking may also produce gainful results.

There is also the aspect of increasing the quantity of good quality manure that would obviously involve improving the quality and quantity of feeding. An improved feeding regime is likely to increase offtake rate, which will in turn reduce the inefficiency involved in keeping livestock through several seasons, the same livestock which are losing weight in the dry season and regaining it in the wet season, at the expense of resources that could raise other animals. Quantifying the productivity of livestock manure by using data from a single cross-section is difficult especially because of the various factors that affect yield response across ecologies and farming systems. Panel data collection and analysis for up to a 3–5 year period, in this respect, may be necessary to reasonably quantify this aspect of the contributions of livestock to farm efficiency and productivity.

The 56 best performing farms, representing 10% of the sample, operated at an average economic efficiency of 85% while the average performance for all farms was 63%. The difference of 22% presents the opportunity that agricultural productivity in the savannah zones of West Africa could be improved through the improvement of economic efficiency alone. And this is a conservative estimate because it is based on a thick frontier involving 10% of the best performing farms rather than on the real frontier farm that scored a 100%. The characteristics of the top performing farms point to smaller farms, the use of more manure than chemical fertilisers, ownership of more livestock per hectare, increased number of years of continuous cropping and the involvement of youths in farming as the pathways for increasing economic efficiency of farms in savannah West Africa.

Increasing agricultural productivity, even within the framework of the guidelines provided by this study, will depend on how seriously extension services are taken and their programmes carried out. Going by recent studies in the West Africa on the performance of extension systems, a lot still needs to be done should extension systems be the preferred route of reaching farmers with new technologies including information.

4 Assessing potential for improving efficiency: An extension of the frontier model

[4.1 Specification of the model](#)

[4.2 Results and discussion](#)

[4.3 Quantifying the impacts of alternative resource use options](#)

[4.4 Summary](#)

The current level of farm efficiency is low and varying, so substantial gains in productivity can be made through the reallocation of existing resources, and introducing new technology by targeting farms accordingly (Chapter 3). Raising average performance of farms translates directly into agricultural productivity growth. For example a 20% gain in average efficiency could mean an improvement of the growth rate in agriculture in SSA from the current 1.5% to as much as 1.8%, thus raise the income and standard of living of poor farmers (SLP 1999; Okike 2000).

In this section, extending the frontier model results from Chapter 3, an assessment of the possible ways of improving the level of efficiency through selected interventions under given farm conditions will be made. Such knowledge is expected to guide policy makers, extension and development agencies to design interventions for improving the performance of the agricultural sector. The results of the frontier model will be used to classify farms into efficient and inefficient groups using a threshold level of performance. A logistic regression model will be used to identify the factors contributing to efficiency or inefficiency. The logistic model will be further modified to assess the probability of success for achieving higher level of efficiency with the interventions identified by the initial logistic model.

4.1 Specification of the model

Conventionally, the stochastic frontier function technique is used to obtain economic efficiency indices for a sample of farms. Then OLS regression is used to determine factors contributing to efficiency levels. However, rather than using efficiency level as a continuous dependent variable in an OLS regression to identify factors influencing efficiency, the indices can be converted into a binary variable by classifying farms into efficient and inefficient categories by using a target efficiency level as the cutting point. For simplicity, the sample average efficiency level can be used as the cutting point and farms with below average efficiency may be classified as inefficient and those above average as efficient. Then efficiency can be used as a binary dependent variable in a logistic regression of the general form (Norusis 1993):

$$\text{Probe (event)} = \frac{e^Z}{1 + e^Z} \quad (8)$$

where Z is the linear combination

$$Z_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n \quad (9)$$

The coefficient of is the log of the odds or logit, i.e. the ratio of the probability that an event will occur to the probability that it will not, and Xs are factors influencing the event.

Then the probability of inefficient farms crossing a predetermined threshold economic efficiency value can

be predicted by modifying the intensity of use of relevant resources (covariates) that are identified as significantly contributing to efficiency. This was the procedure applied in this chapter.

The empirical model involved the following sequence of operations. First, based on the efficiency level generated by the frontier model in Chapter 3, a binary dependent variable for efficient farm or inefficient farm (EEFARM_i) was derived for use in the logistic regression model, as follows:

$$\text{or} \quad \begin{aligned} \text{EEFARM}_i &= 1 \left\{ \text{if } \exp(\mu_i) \geq \left[\exp(\mu)^* + \phi \right] \text{ for all the } i, i = 1, 2, \dots, n \right\} \\ \text{EEFARM}_i &= 0 \left\{ \text{if } \exp(\mu_i) < \left[\exp(\mu)^* + \phi \right] \right\} \end{aligned} \quad (10)$$

where $\exp(\mu)^*$ is evaluated at the current average economic efficiency of the sample and is the j value by which the current average economic efficiency has to be raised to attain a new average economic efficiency. Thus, EEFARM_i = 1 defines the efficient farm operating at the new average economic efficiency level or above, while EEFARM_i = 0 is for the inefficient farm whose economic efficiency level is below the new average.

Then a logistic regression model of the form in equation (8), is substituted where:

$$Z_i = \sum \phi_i D_i + \sum a_j V_{jt} \quad (11)$$

and D_i = dummy for the j^{th} categorical variable V_{jt} = the j^{th} covariate for the t^{th} observation, $t = 1, 2, \dots, T$; ϕ_i = logit for categorical variables for the i^{th} stratum of farms, $i = 1, 2, \dots, I$; while a_j = logit for the j^{th} covariate, $j = 1, 2, \dots, J$.

The dependent variable, farm economic efficiency (EEFARM), is as already defined. Since the percentage economic efficiency of farms cannot take a value below zero, this truncated normal distribution makes estimation by logistic regression appropriate.

Five criteria were used in stratifying the sample, consequently we have five categorical variables, namely: socio-economic domain (defined earlier), manure use (yes/no), fertiliser use (yes/no), animal traction use (yes/no), and membership to farmer co-operative society (yes/no). The covariates are farm size (ha); hired labour (persondays); household labour (persondays); other costs representing expenditure on seeds, agrochemicals and crop residue as animal feed (₦); age of household head (years); percent of farm area under crop legumes—mainly cowpea and peanuts (%); percent of livestock income in gross revenue (%); household size (number); land use intensity (years of continuous cropping of farmland before fallowing); and number of tropical livestock units (TLU) owned.

In the final stage of the analyses, the results from logistic regression models were applied to quantify and predict the effects of different interventions, which modify the magnitude of the statistically significant factors. In the dichotomous linear probability model a_j measures the effect on $P(\text{EEFARM} = 1)$ of a unit change in V_j , and this effect is similar for all values of V_j and all values of V_{jt} since we consider a linear model. In the logistic regression model, the above relationship is non-linear and, therefore, the interpretation of the impact of a change in V_j on $P(\text{EEFARM} = 1)$ is not as straightforward. Characteristically, when the value of Z is large and negative, $P(\text{EEFARM} = 1)$ increases only slowly with increasing Z ; when Z is near zero the rate of change in $P(\text{EEFARM} = 1)$ is high, while at large and positive values of Z , the rate of change in $P(\text{EEFARM} = 1)$ with Z is again small. Thus a_j determines the direction of effect of change of $P(\text{EEFARM} = 1)$ with respect to V_j while the magnitude of the effect of that change depends upon the magnitude of Z_t , which in turn depends upon the magnitude of all V_{jt} .

In the above circumstances, quantifying the impacts of V_j on $P(\text{EEFARM} = 1)$ often requires that some interesting specific values of the explanatory variables are selected and used to compute their corresponding $P(\text{EEFARM} = 1)$ values. In this way, the change in stimulus DZ , and the change in $P(\text{EEFARM} = 1)$, due to a change in V_j , DV_j , can be calculated. For this study we have used the average values of the significant explanatory variables as the baseline and calculated fresh values for them in order to trace the decision responses of the farmers along full sigmoid curves, symbolic of logistic regression models (Figure 3). This also provides a simulation of the impacts of implementing some selected interventions.

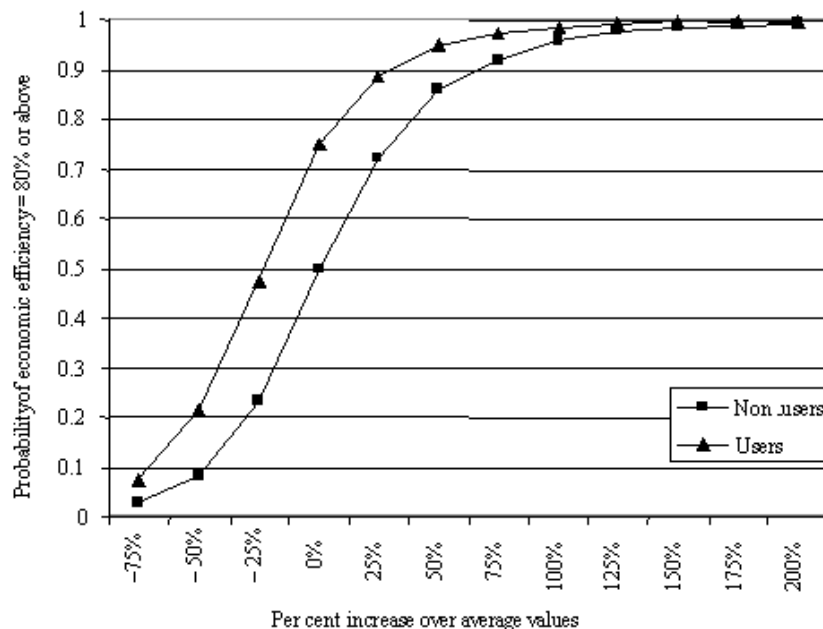


Figure 3. Probability of attaining economic efficiency of 80% or above for users and non-users of manure, with other factors remaining the same.

The parameters of the logistic regression model were estimated using the backward conditional stepwise option for logistic regression available in a prepackaged computer software, SPSS® version 9.0. Testing for endogeneity has been done using Hausman procedure (Hausman 1978) and where appropriate, predicted rather than observed values were used to overcome the problem of endogeneity.

4.2 Results and discussion

The average economic efficiency of the sample farms was 60.3% (Table 6). The least efficient farm operated at 11.4% economic efficiency rating while one farm operated at the frontier, i.e. 100% economic efficiency. Fifty per cent of the sample farms operated at above average efficiency and 26.8% operated at 50–59% efficiency.

From equation (6), and assuming a policy objective of raising average economic efficiency in savannah West Africa to 80% and above as obtainable in many other regions (Bravo-Ureta and Rieger 1991; Dawson et al. 1991; Deb and Hossain 1995; Parikh et al. 1995), then $j @ 20\%$ because $\exp(m)^* = 60.3\%$ evaluated at the mean value of current economic efficiency levels. The results show that 66 farms or 11.8% of the farms surveyed, qualify to be classified as efficient farms as defined by $\text{EEFARM}_i = 1$ for $\text{EFF}_i \geq 80\%$.

Table 9 presents the MLE coefficients of the prototype (initial) and constrained (final) models of the logistic regression analysis. The prototype model had 5 categorical variables and 10 covariates, which were distilled through the backward conditional stepwise method to obtain the constrained model, which has only 1 categorical variable and 8 covariates. The categorical variables for membership of co-operative society, socio-economic domains, fertiliser use and animal traction use were eliminated from the prototype model on steps 2, 3, 4 and 7 while the covariates for farm size and household size were removed on steps 4 and 5. The prototype model could be used to predict 95% correctly whether a farm in

savannah West Africa, which the survey area represents, is likely to attain economic efficiency of 80% and above or not.

Table 9. Results of the logistic regression analysis.

Variables	Prototype model Coefficient (s.e)	Constrained model Coefficient (s.e)	Constrained mode Exp (b)
Intercept ¹	−0.118 (1.137)	−0.018 (0.989)	–
Categories			
Socio-economic domains			
NGS LPHM	−0.673 (1.116)	–	–
NGS HPLM	−0.869 (1.128)	–	–
NGS HPHM	−0.908 (1.165)	–	–
SS LPLM	−0.385 (1.074)	–	–
SS LPHM	0.356 (1.074)	–	–
SS HPLM	−0.671 (1.063)	–	–
SS HPHM	0.447 (0.798)	–	–
Manure users	0.776 (0.798)	1.097* (0.657)	2.994
Fertiliser users	−0.365 (0.648)	–	–
Animal traction users	0.563 (0.642)	–	–
Co-operative society members	−0.053 (0.603)	–	–
Covariates			
Farm size	0.045* (0.027)	–	–
Hired labour (persondays/ha)	0.064*** (0.012)	0.061*** (0.010)	1.063
Household labour (person days/ha)	0.068*** (0.009)	0.062*** (0.008)	1.064
Other costs (₦/ha) ²	−0.000001 (0.000001)	−0.000001 (0.000001)	1
Age of respondent	−0.271*** (0.046)	−0.267*** (0.041)	0.766
Farm under crop legumes (%)	1.947** (0.990)	2.001** (0.840)	7.393
Livestock income in revenue (%)	−1.523** (0.756)	−1.594** (0.694)	0.203
Household size	−0.018 (0.038)	–	–
Years of continuous cropping	0.151*** (0.038)	0.166*** (0.032)	1.18
Livestock owned (TLU/ha)	0.229 (0.046)	0.214*** (0.040)	1.239
Goodness of fit parameters	Values	Values	
Correct classification of low efficiency farms (%)	98.43	97.99	
Correct classification of high efficiency farms (%)	81.48	84.26	
Overall correctness in classification (%)	95.14	95.32	
Model ³ c ²	410.92	403.15	
<p>1. The intercept for the prototype model is based on NGS LPLM domain, non-users of manure, fertilisers and animal traction; and non-members of co-operative societies. That of the constrained model has only non-users of manure in addition.</p> <p>2. US\$ 1 = ₦ 85 at the time of field survey.</p> <p>3. Model c² = −2LL with only constant in the model less −2LL with constant and variables (critical c² values at the 10%, 5% and 1% levels of significance with nine degrees of freedom are 14.68, 16.92 and 21.67, respectively).</p> <p>***, ** and * indicate 1%, 5% and 10% levels of significance.</p> <p>NGS = Northern Guinea savannah; SS = Sudan savannah; LPLM = low-population–low-market; LPHM = low-population–high-market; HPLM = high-population–low-market; HPHM = high-population–high-market.</p>			

Farms likely to operate below 80% economic efficiency are classified more accurately (98%) than farms

of high economic efficiency (81%). The prototype model c^2 value of 410.92 is higher than the critical c^2 value of 38.93 at 1% level of significance with 21 degrees of freedom indicating that the variables included in the model are useful in predicting economic efficiency classes and the probability of a change from one class to the other. The values of the goodness of fit parameters are similar for the constrained model suggesting that any of the two models presented in Table 8 could serve our purpose. However, the need for sharper policy focus led to the choice of the constrained model especially since a joint hypothesis test for both models indicated that the categorical variables and covariates eliminated from the prototype model to obtain the constrained model are of no statistical value. This means to say that since the difference in-2LL between both models, i.e. 7.77 is lower than the critical c^2 value of 18.55 at 10% level of significance with 12 degrees of freedom, the hypothesis that the coefficients of the excluded variables are jointly equal to zero is accepted. Based on the above, further applications of the results of the logistic regression model in this paper will be limited to the constrained model. For this reason, only the $exp(b)$ of the coefficient of the variables in the constrained model appears in Table 9.

Of the five categorical variables, only the stratification by users and non-users of manure was retained in the stepwise selection process up to the constrained model, and beyond—until no more variables could be added or deleted. Manure had, in earlier studies, been described as the hub of crop–livestock interactions with crucial roles to play in sustainable agricultural intensification (McIntire et al. 1992; Murwira et al. 1995; Smith et al. 1997; Powell and Valentin 1998; Okike 2000). Its resilience in the logistic regression model and emergence as the single most important factor in classifying and predicting farm-level economic efficiency lends further credence to the above notion and points it out as a key resource for improving farm efficiency and consequently, improving the livelihoods of farmers.

From Table 9, the value of the $exp(b)$ for manure indicates that switching a farm from non-use to use of manure increases the odds of that farm being economically efficient three times. Planting all farms to leguminous crops has the highest odds. However, it is unrealistic to expect all farms to have cowpea and groundnuts as the only crops grown even though this action increases the ratio of the probability of farms being economically efficient to the probability of being inefficient by as much as seven times. Expenditure on seeds, agrochemicals, agricultural implements and crop residues (other costs) has a neutral effect on efficiency, so it suggests that lack of appropriate technologies for farming cannot be seriously implicated for low productivity and low efficiency of some farms in SSA.

The higher the share of livestock income in revenue, the lower the economic efficiency. This is not surprising because efficiency is expected to be lower for agropastoralists than for mixed farms, who have a lower share of livestock revenue in a given farm revenue. As agropastoralists evolve into mixed farmers, higher interaction through higher use of manure and draft power application per unit of cropland contributes to higher efficiency in mixed farms.

4.3 Quantifying the impacts of alternative resource use options

Table 10 summarises the ways in which changes in various combinations of resources from the current combinations affect the probability of a farm being economically efficient. Modest and practicable changes were made to the magnitude of the covariates in the constrained model in Table 9, using their mean values as the basis for the changes. In remaining as practical as possible in modelling the impacts, no changes were made to the average age of the respondent, household labour and costs. Although the results show that younger farmers are needed to improve efficiency, there is no way of reducing the age of the existing farmers as time passes and their replacement by younger ones cannot be reasonably expected in the very short run. Household labour is more or less a fixed resource, especially in the short run. So as resource use intensification occurs, the farm household is left with little alternative than to hire labour. Recall that the $exp(b)$ for other costs was exactly 1, so increasing or decreasing miscellaneous expenditure may or may not improve economic efficiency. Given these circumstances, it was considered most appropriate to place a constraint on household labour, age of respondent and costs within their mean values. In modelling alternative pathways, hired labour was allowed to increase freely up to 250% or 58 persondays/ha; TLU has been constrained to increase from 2.6 to 3.9 or by 150%; continuous cropping may take place for up to 21 years; and the share of livestock income in gross revenue could be allowed to drop from 28% to 21%, in the early stages.

Table 10. *Quantifying the implications of alternative resource use options for farm economic efficiency.*

	Increase over current average of resources to achieve
--	---

Scenarios	various Pr (Y=1)(%)					
	HL	TLU	LIVREV	CCROP	Pr (Y = 1)	DPr (Y = 1)
For non-users of manure						
A	25	25	-25	10	0.72	0.22
B	50	50	-25	20	0.86	0.36
C	75	50	-25	25	0.92	0.42
D	100	50	-25	40	0.96	0.46
E	125	50	-25	50	0.98	0.48
F	150	50	-25	50	0.98	0.48
For users of manure						
A1	Same scenario as in A above				0.89	0.39
B1	Same scenario as in B above				0.95	0.45
C1	Same scenario as in C above				0.97	0.47
D1	Same scenario as in D above				0.99	0.49
E1	Same scenario as in E above				0.99	0.49
F1	Same scenario as in F above				0.99	0.49
HL = hired labour; TLU = tropical livestock unit; LIVREV = share of livestock income in revenue; CCROP = years of continuous cropping; Pr (Y = 1) = probability of economic efficiency ³ 80%; DPr (Y = 1) = change in probability of economic efficiency ³ 80% over average.						

The similar scenarios created in Table 10 for manure users and non-users showed that manure users have a higher probability of being economically efficient, e.g. similar changes as in A and A1, increase the probability of a non-user farm becoming economically efficient by 0.22 while for a user farm it is 0.39. This is illustrated in Figure 3, which also shows that farming systems in savannah West Africa can still accommodate resource use intensification of up to 125% over current average rates, within limits of economic efficiency. So, in terms of economic efficiency and even envisaged impacts of intensification on the environment, we agree with Staal et al. (2001) that the contribution of intensive livestock production to soil fertility through manure is still within the 'win-win' range.

4.4 Summary

Results indicated that manure is the key resource for improving farm economic efficiency. Compared to many previous results on factors affecting economic efficiency obtained from the conventional second stage of stochastic frontier functions, our results show very important gains in insights for policy decisions. These results show that change in efficiency is large and could translate into an increase in agricultural growth rate in SSA—from the present 1.5% (World Bank 1997) to at least 1.9%. Okike (2000) estimated that a 20% increase from the current 60% average economic efficiency of farms would lead to the achievement of the above objective. Thus the methodology offers flexibility for modelling pathways to economic efficiency and affords policy makers options for selecting, *a priori*, any threshold of economic efficiency they consider desirable and achievable.

Further studies could pursue an improvement in the efficiency of the coefficients obtained from the second stage of this method as should be expected if the entire model were to be estimated in a single, automated, MLE procedure as in FRONTIER 4.1 (Kumbhakar et al. 1991; Coelli 1994).

An improvement in the quantity and quality of manure supply is fundamental to the success of this scheme. Achieving this would involve, among others, further expansion of livestock population in the more feed abundant NGS areas of the study zone through reducing disease challenge and encouraging crop–livestock integration. The same increases in stocking rates are not recommended for implementation in the SS where they could entail adverse environmental consequences (Naazie and Smith 1998). Better feeding strategies to enhance manure quality, and proper handling of the manure obtained to ensure minimal losses in nitrogen, carbon and phosphorus would also be required (Eghball et al. 1997). Proper handling of manure needs to include farmer education on appropriate storage conditions, timing and frequency of application, and manure-urine and manure-fertiliser synergies (Schlecht et al. 1998).

References

- Aigner D.J., Lovell C.A.K. and Schmidt P. 1977. Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics* 6:21–37.
- Anon. 1998. Livestock are key to improving soil fertility. *International Agricultural Development* September/October: 11–12.
- Battese G.E. and Coelli T.J. 1992. Frontier production functions, technical efficiency and panel data: With application to paddy farmers in India. *Journal of Productivity Analysis* 3:153–169.
- Battese G.E. and Coelli T.J. 1993. *A stochastic frontier production function incorporating a model for technical inefficiency effects*. Working Papers in Econometrics and Applied Statistics 69. Department of Econometrics, University of New England, Armidale, Australia. 42 pp.
- Boserup E. 1965. *The conditions of agricultural growth: The economics of agrarian change under population pressure*. Aldine Publishing, New York, USA. 124 pp.
- Boserup E. 1981. *Population and technological change: A study in long term trends*. University of Chicago Press, Chicago, Illinois, USA. 194 pp.
- Bravo-Ureta B.E. and Rieger L. 1991. Dairy farm efficiency measurement using stochastic frontiers and neoclassical duality. *American Journal of Agricultural Economics* 73:421–428.
- Brunner J., Henninger N. and Deichmann U. 1995. West Africa Long Term Perspective Study (WALTPS). Database and users guide. World Resources Institute, Washington, DC, USA, and Club du Sahel, Paris, France. (unpublished). v.p. jakeb@wri.org
- Carswell G. 1997. *Agricultural intensification and rural sustainable livelihoods—A think piece*. Working Paper 64. Institute of Development Studies, University of Sussex, Brighton, UK. 27 pp.
- Coelli T.J. 1994. *A Guide to Frontier Version 4.1: A Computer Program for stochastic frontier production and cost function estimation*. Department of Econometrics, University of New England, Armidale, Australia. 34 pp. (Mimeo).
- Coelli T.J. 1995. Recent developments in frontier estimation and efficiency measurement. *Australian Journal of Agricultural Economics* 39:219–245.
- Coelli T. and Battese G.E. 1996. Identification of factors which influence the technical inefficiency of Indian farmers. *Australian Journal of Agricultural Economics* 40(2):103–128.
- Dawson P.J., Lingard J. and Woodford C.H. 1991. A generalized measure of farm-specific technical efficiency. *American Journal of Agricultural Economics* 73:1098–1104.
- Deb U.K. and Hossain M. 1995. Farmers' education, modern technology and technical efficiency of rice growers. *Bangladesh Journal of Agricultural Economics* 18(2):1–13.
- Eghball B., Power J.F., Gilley J.E and Doran J.W. 1997. Nutrient, carbon, and mass loss during composting of beef cattle feedlot manure. *Journal of Environmental Quality* 26(1):189–193.
- Ehui S. and Polson R. 1992. A review of economic and ecological constraints on draft

cultivation in sub-Saharan Africa. *Soil and Tillage Research* 27(1–4):195–210.

Ehui S.K. and Jabbar M.A. 1997. A framework for evaluating the sustainability and economic viability of crop–livestock systems in sub-Saharan Africa. In: Rose R., Tanner C. and Bellamy M.A. (eds), *Issues in agricultural competitiveness: Markets and policies*. IAAE (International Association of Agricultural Economists) Occasional Paper 7. Dartmouth Publishing Co., Aldershot, UK. pp. 406–414.

FAO (Food and Agricultural Organization of the United Nations). 1980. *Terminology of climatic zones in relation to length of growing period (LGP)*. Land and Water Division, file notes, 3 April 1990. FAO, Rome, Italy. 23 pp.

Farrel M.J. 1957. The measurement of production efficiency. *Journal of Royal Statistical Society* 120:253–281.

FDL & PCS (Federal Department of Livestock and Pest Control Services). 1992. *Nigerian livestock resources. Volume 1: Executive summary and atlas*. FDL & PCS and Resource Inventory and Management Limited, St. Helier, Jersey, UK. 440 pp.

Greene W.H. 1990. A gamma-distributed stochastic frontier model. *Journal of Econometrics* 46:141–163.

Hausman J.A. 1978. Specification tests in econometrics. *Econometrica* 46(6):1251–1271.

Hayami Y. and Ruttan V. 1985. *Agricultural development: An international perspective*. Johns Hopkins University Press, Baltimore, Maryland, USA. 506 pp.

Heertje A. 1977. *Economics and technical change*. Weidenfeld and Nicolson, London, UK. 334 pp.

Hoch I. 1958. Simultaneous equation bias in the context of the Cobb-Douglas production function. *Econometrica* 26:566–758.

Hoch I. 1976. Returns to scale in farming: Further evidence. *American Journal of Agricultural Economics* 58:745–749.

Inaizumi H., Singh B.B., Sanginga P.C., Manyong V.M., Adesina A.A. and Tarawali S. 1999. *Adoption and impact of dry-season dual-purpose cowpea in the semi-arid zone of Nigeria*. IITA IMPACT series. IITA (International Institute of Tropical Agriculture), Ibadan, Nigeria. 34 pp.

Islam N. (ed). 1995. *Population and food in the early twenty-first century: Meeting future food demand of an increasing population*. IFPRI (International Food Policy Research Institute), Washington, DC, USA. 239 pp.

Jabbar M.A. 1981. The constraints on employment expansion in crop production in Bangladesh. In: Islam R. (ed), *Employment expansion through local resource mobilisation*. ILO (International Labour Organization), Bangkok, Thailand. pp. 75–81.

Jabbar M.A. 1996. Energy and the evolution of farming systems: The potential of mixed farming in the moist savannah of sub-Saharan Africa. *Outlook on Agriculture* 25(1):27–36.

Jahnke H.E. 1982. *Livestock production systems and livestock development in tropical Africa*. Kieler Wissenschaftsverlag Vauk, Kiel, Germany. 237 pp.

Jondrow J., Lovell C.A.K., Materov I.S. and Schmidt P. 1982. On estimation of technical inefficiency in the stochastic frontier production function model. *Journal of Econometrics*

Kumbhakar S., Ghosh S.C and McGuckin J.T. 1991. A generalised production frontier approach for estimating determinants of inefficiency in U.S. dairy farms. *Journal of Business, Economics & Statistics* 9:279–286.

Manyong V.M., Smith J., Weber G.K., Jagtap S.S. and Oyewole B. 1996. *Macrocharacterization of agricultural systems in West Africa: An overview*. Resource and Crop Management Monograph 21. IITA (International Institute of Tropical Agriculture), Ibadan, Nigeria. 30 pp.

McIntire J., Bourzat D. and Pingali P. 1992. *Crop–livestock interactions in sub-Saharan Africa*. The World Bank, Washington, DC, USA. 246 pp.

Mubarik Ali and Flinn J.C. 1989. Profit efficiency among Basmati rice producers in Pakistan Punjab. *American Journal of Agricultural Economics* 71:303–310.

Murwira K.H., Swift M.J. and Frost P.G.H. 1995. Manure as a key resource in sustainable agriculture. In: Powell J.M., Fernandez-Rivera S., Williams T.O. and Renard C. (eds), *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Volume II. Technical papers. Proceedings of an international conference on livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, Addis Ababa, Ethiopia, 22–26 November 1993*. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. pp. 131–148.

Naazie A. and Smith J.W. 1998. Modelling ruminant feed budgets under land use change in the moist savannahs of sub-Saharan Africa. *Agricultural Systems*. (in press).

Ndubuisi A., Zeddies J., Manyong V.M. and Smith J.W. 1998. Crop–livestock integration along the gradient of resource use intensification in the northern Guinea savannah of Nigeria. *Quarterly Journal of International Agriculture* 37(2):105–115.

Norusis Marija J. 1993. *SPSS for Windows: Advanced statistics*. Release 6. SPSS Inc, Chicago, Illinois, USA. 828 pp.

Ogungbile A.O., Tabo R., van Duivenbooden N. and Debrah S.K. 1998. Analysis of constraints to agricultural production in the Sudan savannah zone of Nigeria using multi-scale characterisation of production systems. Report submitted to ICRISAT (International Crop Research Institute for Semi-Arid Tropics), Patancheru 502 324, Andhra Pradesh, India. 38 pp. (unpublished).

Okike I. 2000. *Crop–livestock interactions and economic efficiency of farmers in the savannah zones of Nigeria*. PhD thesis, University of Ibadan, Ibadan, Nigeria. 155 pp.

Okoruwa V.O., Jabbar M.A. and Akinwumi J.A. 1996. Crop–livestock competition in the West African derived savannah: An application of a multi-objective programming model. *Agricultural Systems* 52:439–453.

Parikh A., Ali F. and Shah M.K. 1995. Measurement of economic efficiency in Pakistan agriculture. *American Journal of Agricultural Economics* 77:675–685.

Pingali P., Bigot Y. and Bingswinger H.P. 1987. *Agricultural mechanization and the evolution of farming systems in sub-Saharan Africa*. The World Bank, Washington, DC, USA. 216 pp.

Powell J.M. and Valentin C. 1998. Effects of livestock on soil fertility in West Africa. In: Renard G., Neef A., Becker K. and von Oppen M. (eds), *Soil fertility management in West African land use systems. Proceedings of a conference on soil fertility management in West African land*

use systems, Niamey, Niger, 4–8 March 1997. Weikersheim, Margraf Verlag, Germany. pp. 319–338.

Reifschneider D. and Stevenson R. 1991. Systematic departures from the frontier: A framework for the analysis of firm inefficiency. *International Economic Review* 32:715–723.

Reynolds L. and de Leeuw P.N. 1995. Myth and manure in nitrogen cycling. A case of Kaloleni Division in Coast Province, Kenya. In: Powell J.M., Fernandez-Rivera S., Williams T.O. and Renard C. (eds), *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Volume II. Technical papers. Proceedings of an international conference held in Addis Ababa, Ethiopia, 22–26 November 1993*. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. pp. 509–521.

Ruthenberg H. 1980. *Farming systems in the tropics*. Clarendon Press, Oxford, UK. 424 pp.

Savadogo K., Reardon T. and Pietola K. 1994. Farm productivity in Burkina Faso: Effects of animal traction and nonfarm income. *American Journal of Agricultural Economics* 76:608–612.

Schlecht E., Mahler F., Sangare M., Susenbeth A. and Becker K. 1995. Quantitative and qualitative estimation of nutrient intake and faecal excretion of Zebu cattle grazing natural pasture in semi-arid Mali. In: Powell J.M., Fernandez-Rivera S., Williams T.O. and Renard C. (eds), *Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Volume II: Technical papers. Proceedings of an international conference on livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa, Addis Ababa, Ethiopia, 22–26 November 1993*. ILCA (International Livestock Centre for Africa), Addis Ababa, Ethiopia. pp. 85–97.

Schlecht E., Fernandez-Rivera S. and Hiernaux P. 1998. Timing, size and nitrogen concentration of faecal and urinary excretions in cattle, sheep and goats: Can they be exploited for better manuring of cropland? In: Renard G., Neef A., Becker K. and von Oppen M. (eds), *Soil fertility management in West African land use systems. Proceedings of a conference on soil fertility management in West African land use systems, Niamey, Niger, 4–8 March 1997*. Weikersheim, Margraf Verlag, Germany. pp. 361–367.

Schmidt P. 1976. On the statistical estimation of parametric frontier production functions. *The Review of Economics and Statistics* 58:238–239.

SLP (System-wide Livestock Programme). 1999. *Programme plan: Feed resources, natural resource management and related policy research*. ILRI (International Livestock Research Institute), Nairobi, Kenya. 19 pp.

Smith J., Barau A.D., Goldman A. and Marek J.H. 1993. The role of technology in agricultural intensification: The evolution of maize production in the northern Guinea savannah of Nigeria. In: Dovarak K.A. (ed), *Social science research in technology development: Spatial and temporal dimensions*. CAB (Commonwealth Agricultural Bureaux) International, Oxon, Wallingford, UK. pp. 144–166.

Smith J.W., Naazie A., Larbi A., Agyemang K. and Tarawali S. 1997. Integrated crop–livestock systems in sub-Saharan Africa: An option or imperative? *Outlook on Agriculture* 26(4):237–246.

Staal S.J., Ehui S. and Tanner J. 2001. Livestock–environment interactions under intensifying production. In: Lee D.R. and Barrett C.B. (eds), *Tradeoffs or synergies? Agricultural intensification, economic development and the environment*. CAB (Commonwealth Agricultural Bureaux) International, Oxon, Wallingford, UK. pp. 345–364.

Tarawali S.A., Smith J.W., Hiernaux P., Singh B.B., Gupta S.C., Tabo R., Harris F., Nokoe S., Fernandez-Rivera S. and Bationo A. 2000. Integrated natural resource management—Putting livestock in the picture. Paper presented at the workshop on integrated natural resource management in the CGIAR: Approaches and lessons. 21–25 August 2000, Penang, Malaysia. 27 pp. (unpublished).

Tiffen M., Mortimore M. and Gichuki F. 1994. *More people, less erosion: Environmental recovery in Kenya*. Wiley, Chichester, UK. 327 pp.

de Wilde J.C. 1967. *Experiences with agricultural development in tropical Africa. Volume 1*. Johns Hopkins University Press, Baltimore, Maryland, USA. 254 pp.

Winrock International. 1992. *Assessment of animal agriculture in sub-Saharan Africa*. Winrock International Institute for Agricultural Development, Morrilton, Arkansas, USA. 125 pp.

World Bank. 1997. *World Development Report*. Oxford University Press, Oxford, UK. 262 pp.